

P5 Workshop on the Future of High Energy Physics

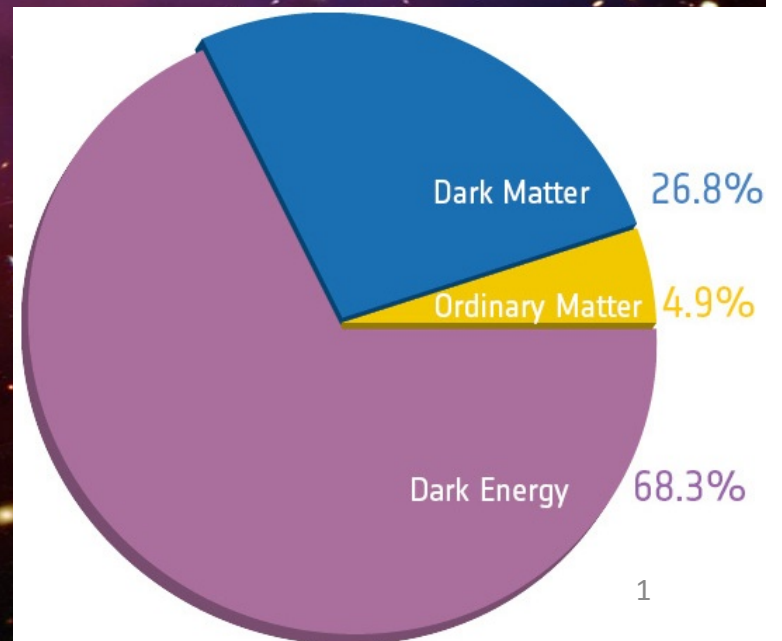
SLAC

December 2, 2013

Direct WIMP Detection

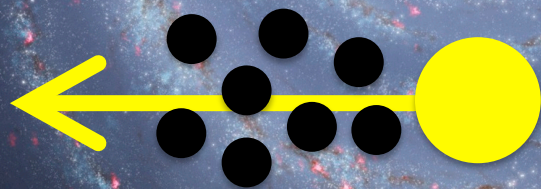
Harry Nelson / UCSB

<http://arxiv.org/abs/1310.8327> (Snowmass CF1)
<http://snowmass2013.org/tiki-index.php?page=SLAC>



Milky Way

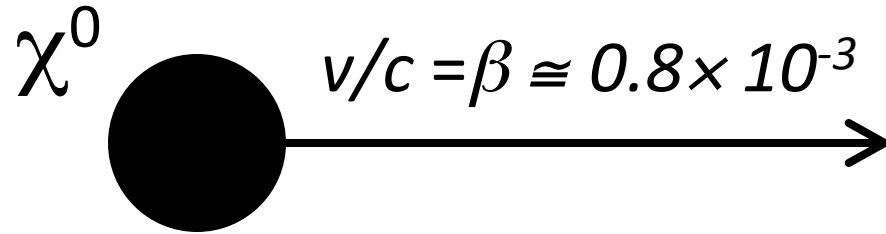
$$n \approx \frac{0.3 \text{ GeV}}{M_D c^2} \frac{1}{\text{cm}^3}$$



Sun

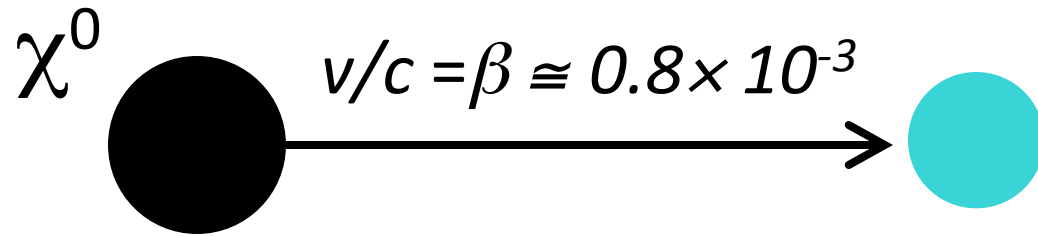
$$\beta \approx 0.77 \times 10^{-3}$$

Billiard Ball Scattering



Massive: $M_\chi c^2 \approx 100 \text{ GeV}$
'Weak Scale'

Billiard Ball Scattering



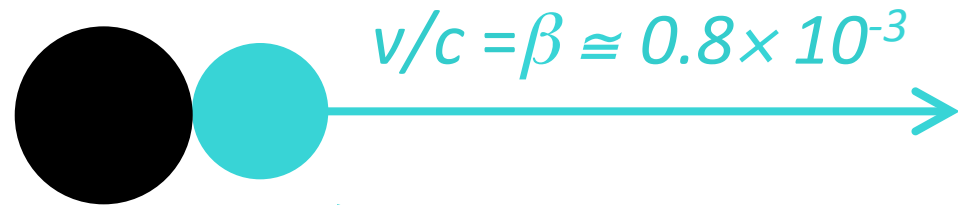
Massive: $M_\chi c^2 \approx 100 \text{ GeV}$
'Weak Scale'

eg Xenon, $A=131$,
 $mc^2=122 \text{ GeV}$

Also: F, Na, Si, Ar, Ge, I, W

Billiard Ball Scattering

χ^0



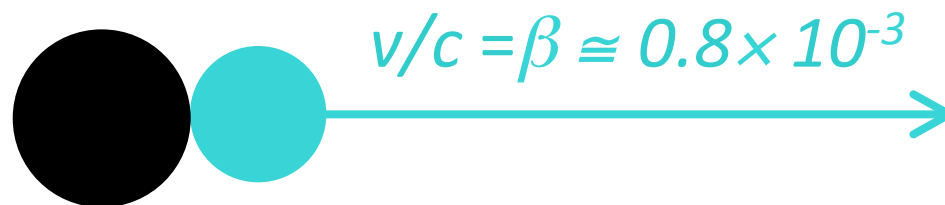
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Billiard Ball Scattering

χ^0



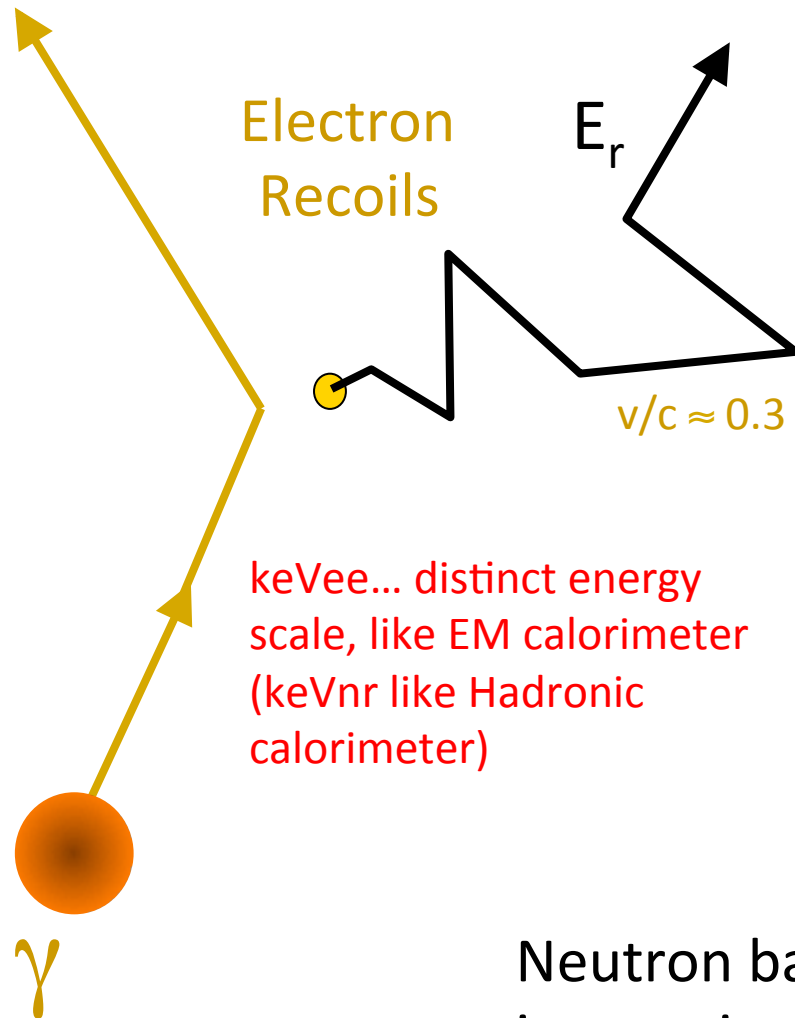
Massive: $M_\chi c^2 \approx 100 \text{ GeV}$
'Weak Scale'

eg Xenon, $A=131$,
 $mc^2=122 \text{ GeV}$

Also: F, Na, Si, Ar, Ge, I, W

$$\begin{aligned} E_R &\approx \frac{1}{2} m_{\text{Xe}} c^2 \beta^2 \\ &\approx (1/4) 122 \text{ GeV} / (10^6) \\ &\approx 30 \text{ keV} \dots \text{keVnr} \end{aligned}$$

Dominant Background

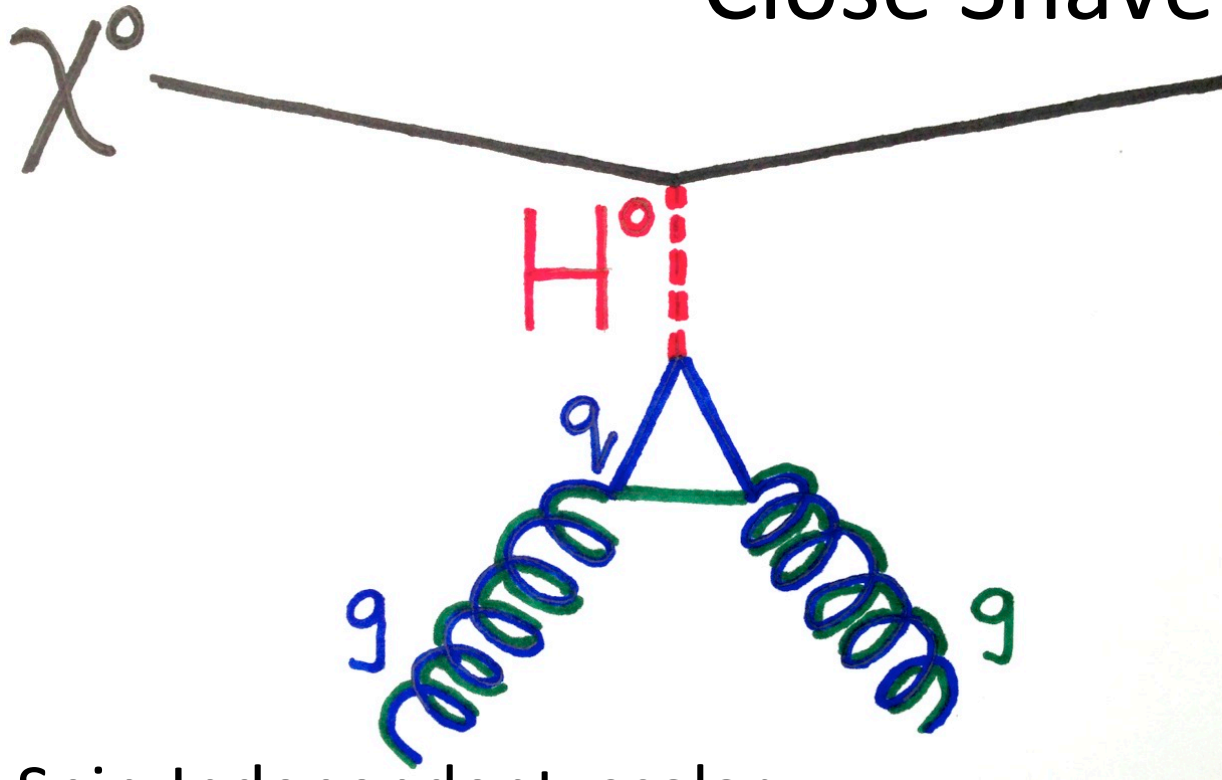


Varieties of Suppression to <1 event:

- 1) Low background materials – historically $\beta\beta/\nu$ 10^2 better
- 2) Self shielding
- 3) Discrimination (aka Particle ID) 10^{-10} to 10^{-2} (but some do none!)
- 4) Astrophysical rate modulation (DAMA)

Neutron backgrounds: low bkgd mat, multiple interactions, depth and/or hydrogenous and active shielding address

Ockham's Razor – Close Shave



Spin-Independent, scalar

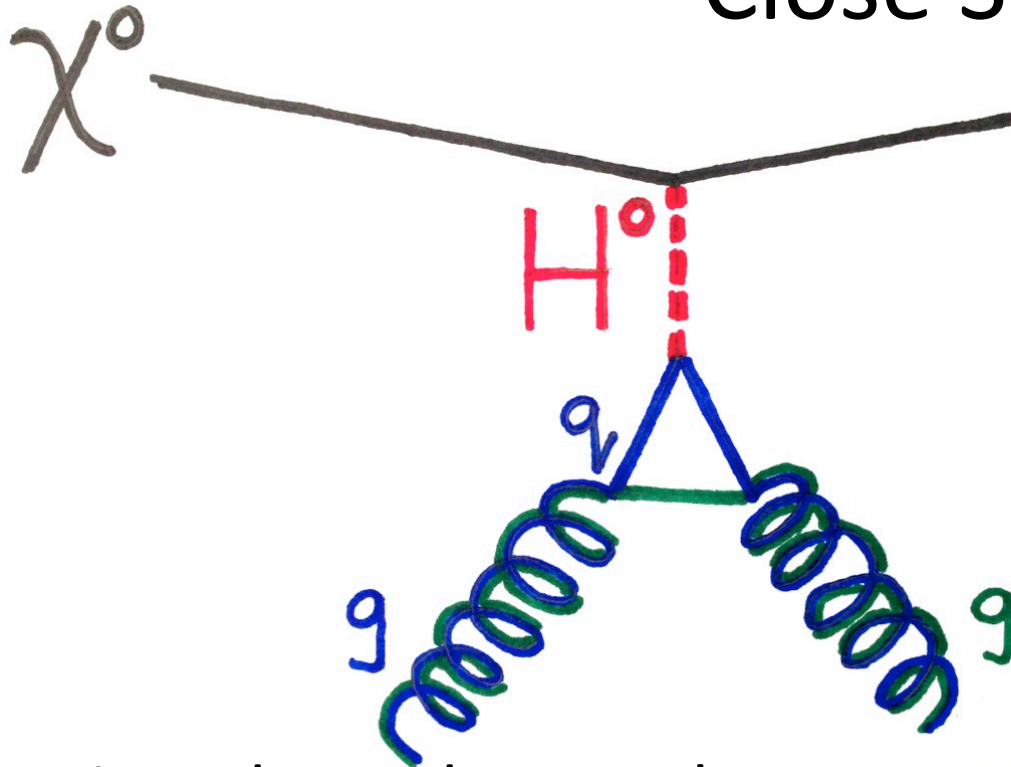
Non-zero for Majorana & Dirac χ^0

Glue n/p indifferent, $\approx A^2$

$$\sigma_{\text{SI}} = 8 \times 10^{-45} \text{ cm}^2 \left(\frac{c_{h\chi\chi}}{0.1} \right)^2$$

Cheung, Hall, Pinner, Ruderman 2013

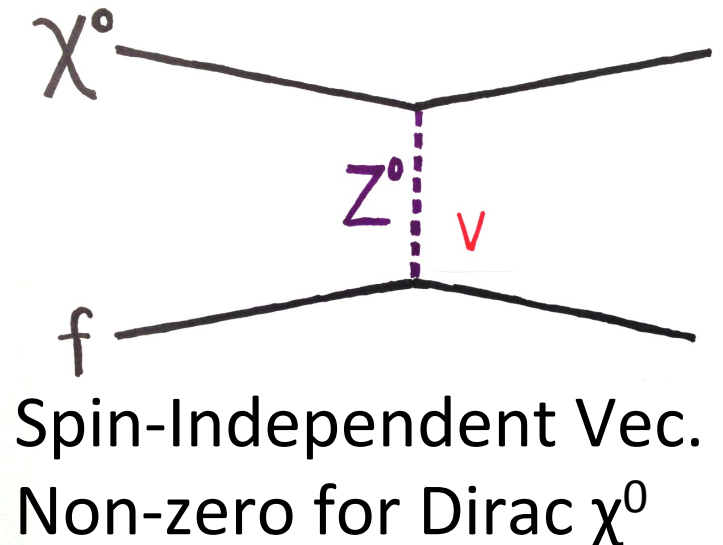
Ockham's Razor – Close Shave



Spin-Independent, scalar
Non-zero for Majorana & Dirac χ^0
Glue n/p indifferent, $\approx A^2$

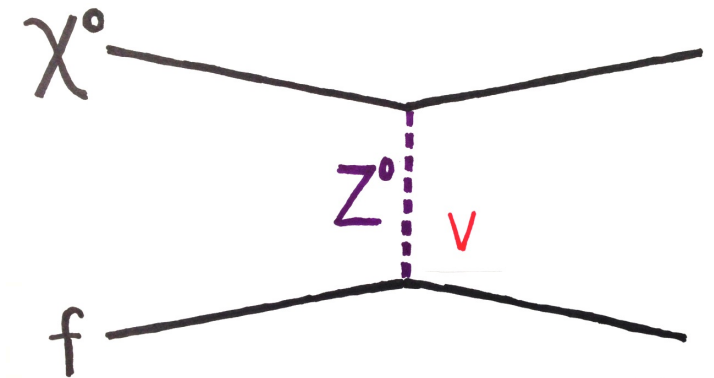
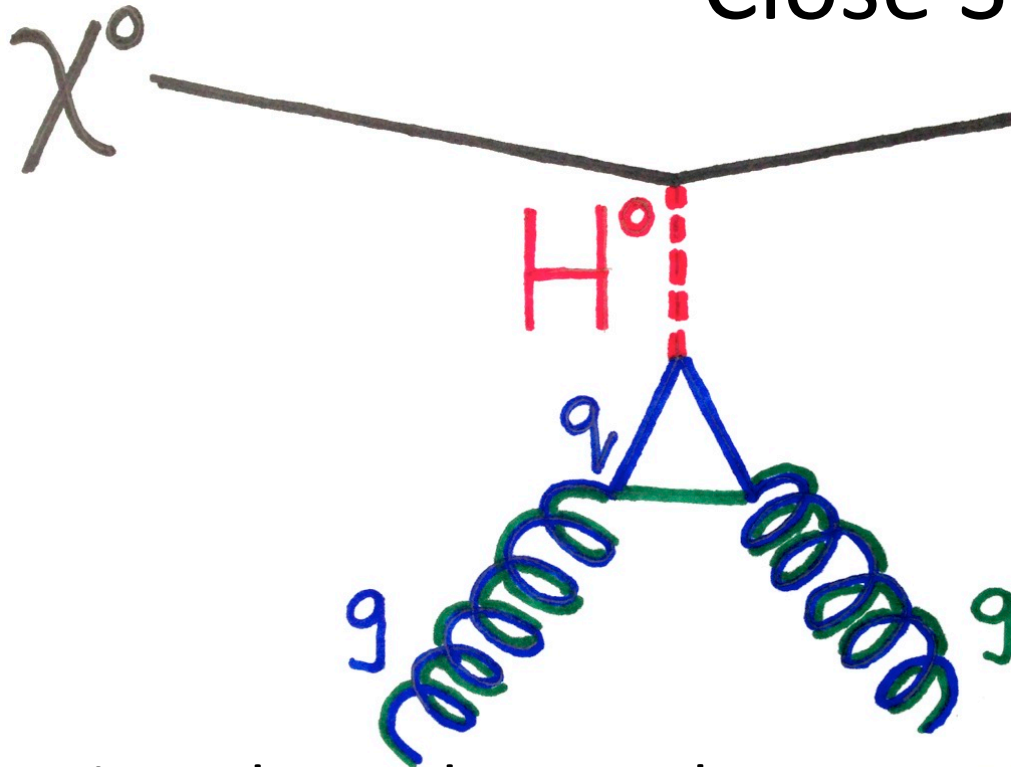
$$\sigma_{\text{SI}} = 8 \times 10^{-45} \text{ cm}^2 \left(\frac{c_{h\chi\chi}}{0.1} \right)^2$$

Cheung, Hall, Pinner, Ruderman 2013



Spin-Independent Vec.
Non-zero for Dirac χ^0

Ockham's Razor – Close Shave



Spin-Independent Vec.
Non-zero for Dirac χ^0

Caution:

Spin-Independent, scalar
Non-zero for Majorana & Dirac χ^0
Glue n/p indifferent, $\approx A^2$

$$\sigma_{\text{SI}} = 8 \times 10^{-45} \text{ cm}^2 \left(\frac{C_{h\chi\chi}}{0.1} \right)^2$$

Cheung, Hall, Pinner, Ruderman 2013

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E. J. KONOPINSKI

In the previously stated conclusion that the h_s and h_t couplings both exist, the quantitative data was not given. Feenberg¹⁵, Mayer, Kofoed-Hansen, Sherr and many others have contributed toward establishing it. Apparently, about all one can now say is that

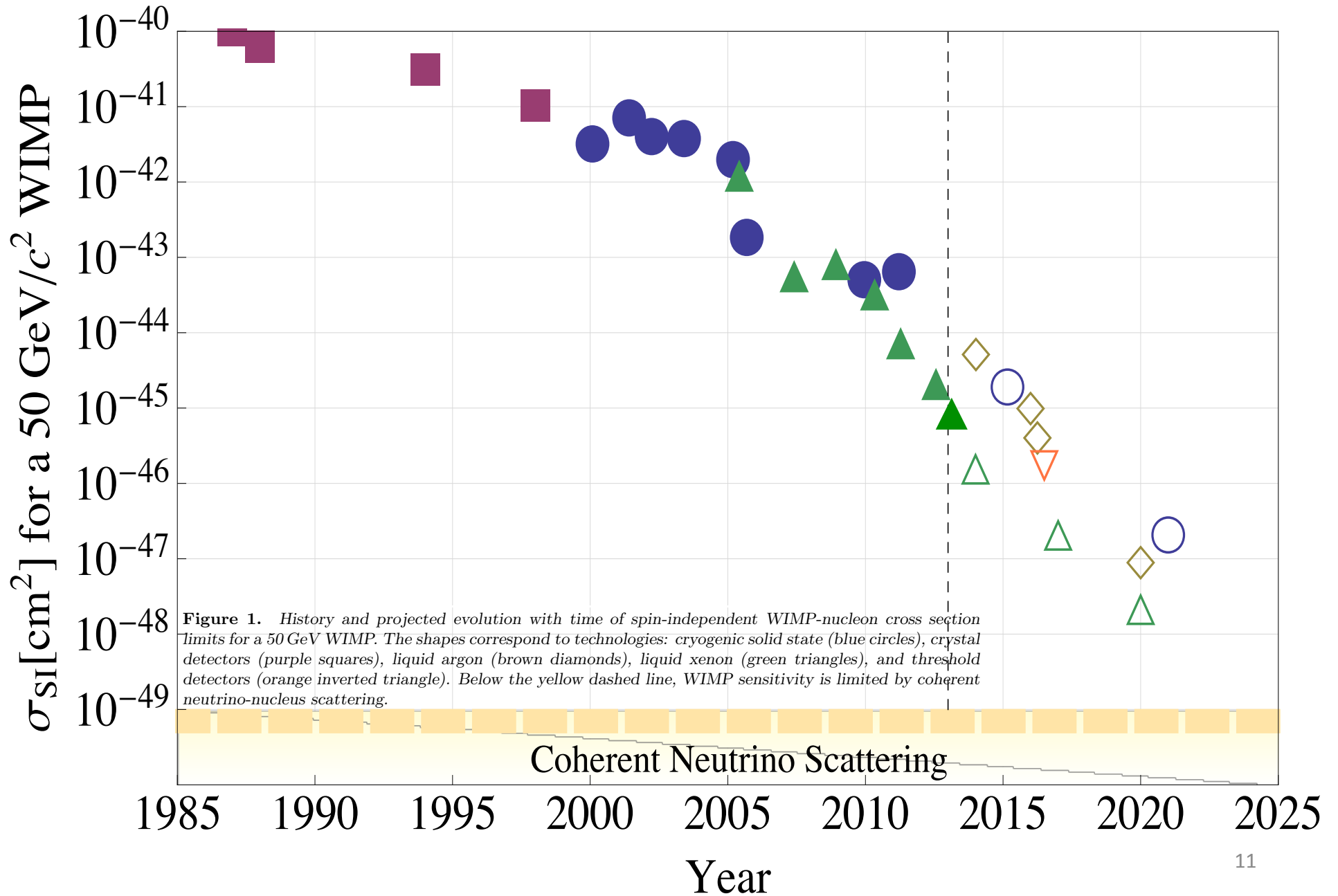
$$g_s^2/g_t^2 = 0.75 \text{ to } 1.15$$

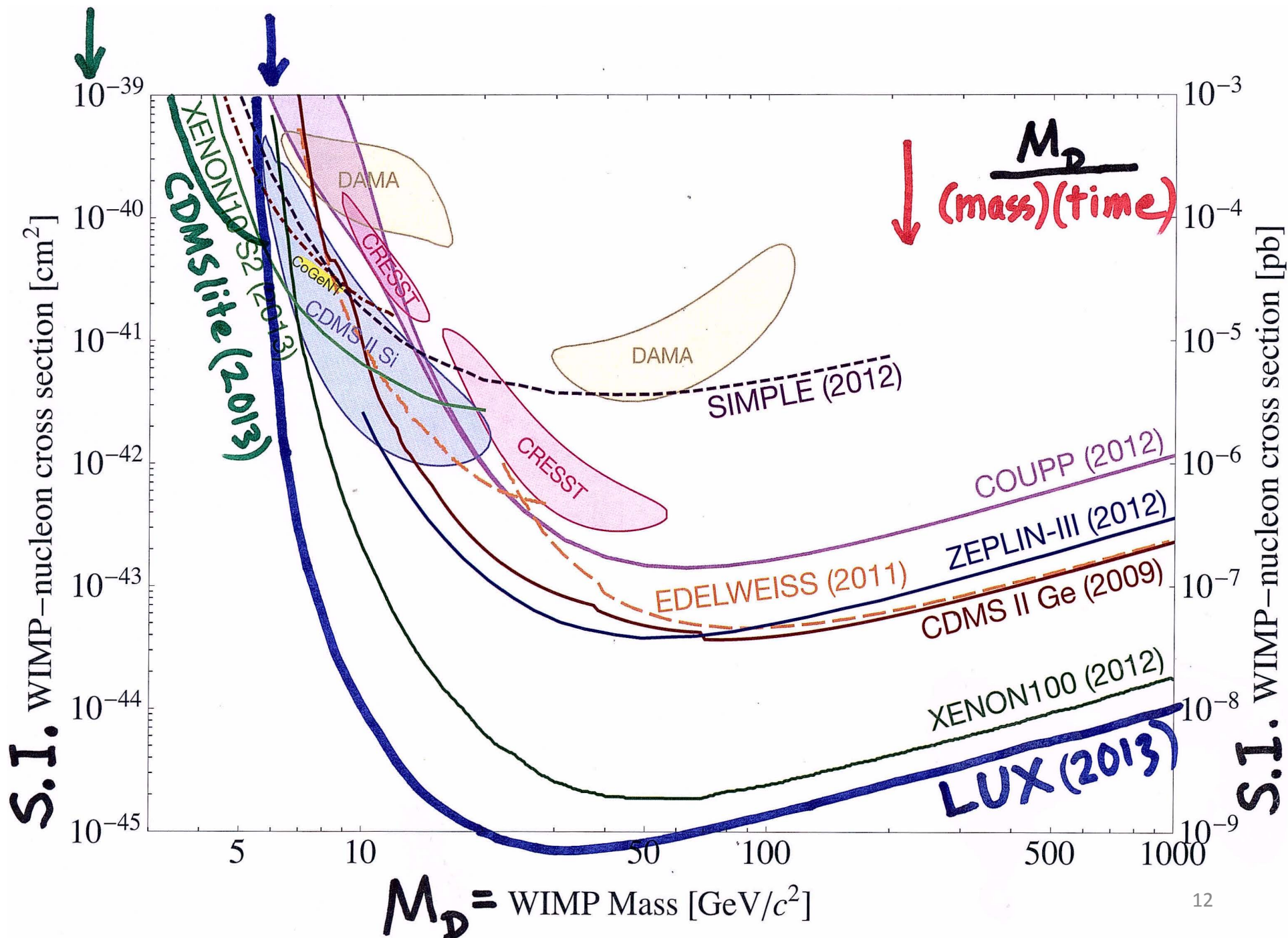
If one supposes $|g_s| = |g_t|$, each equals $1.7 (10)^{-49} \text{ erg-cm}^3$. This still reveals nothing concerning the relative sign of g_s and g_t .

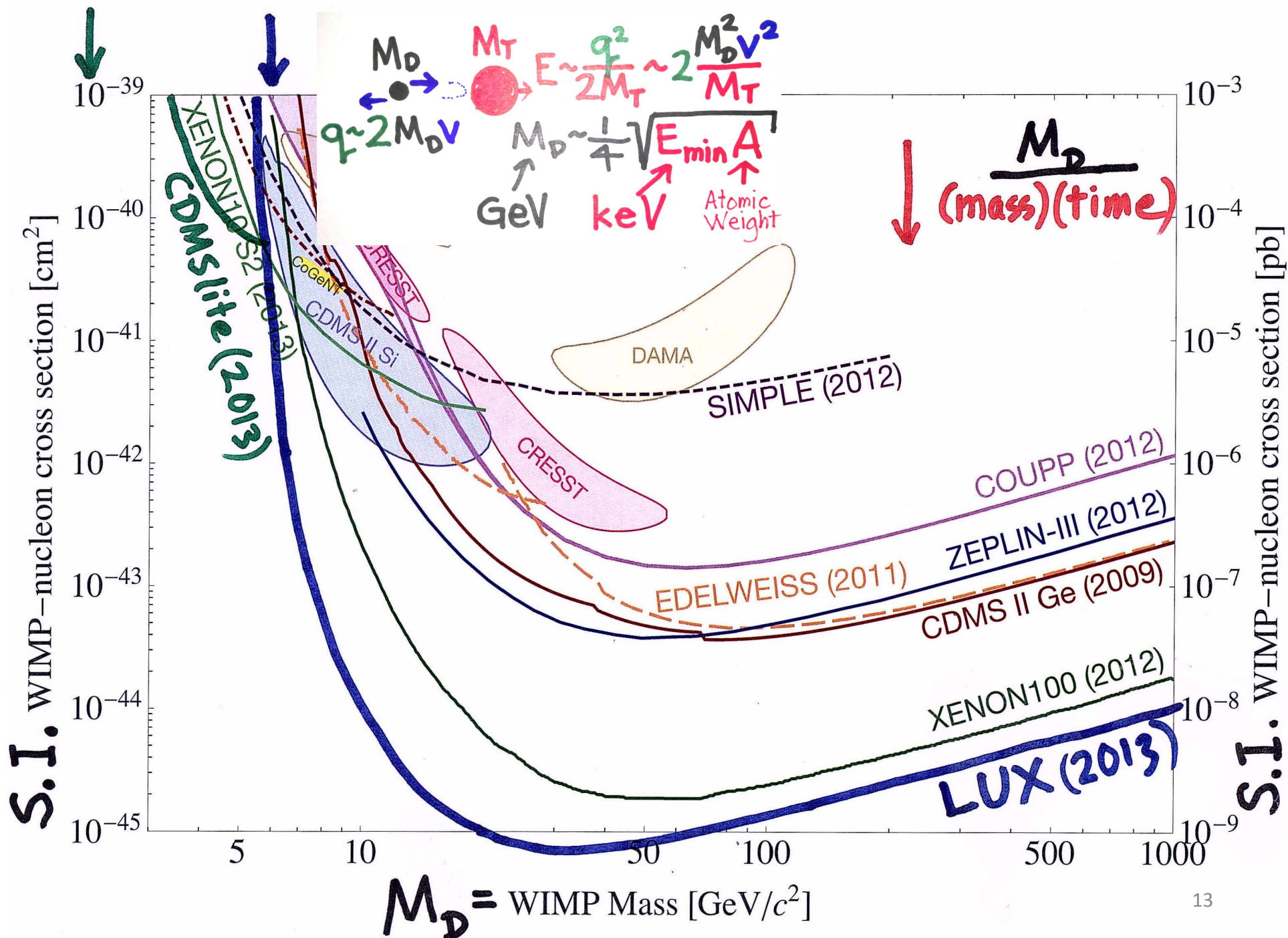
a way to be biguity arises from β -decay g_s and g_t and completely c both $\rho \approx \frac{1}{2}$ as $g_p = 3g_s = 3g_t$,

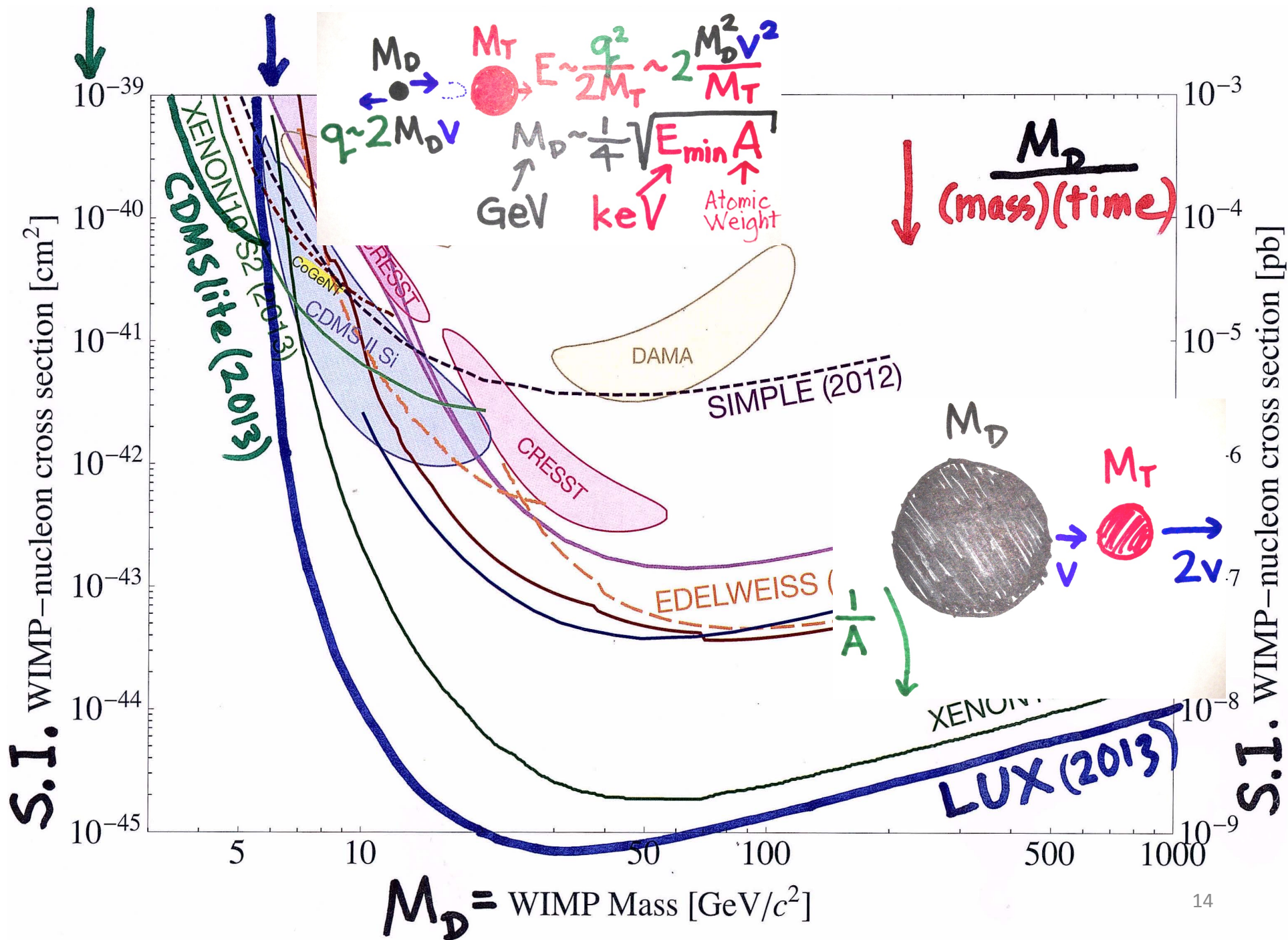
However, t proportions o One may rei

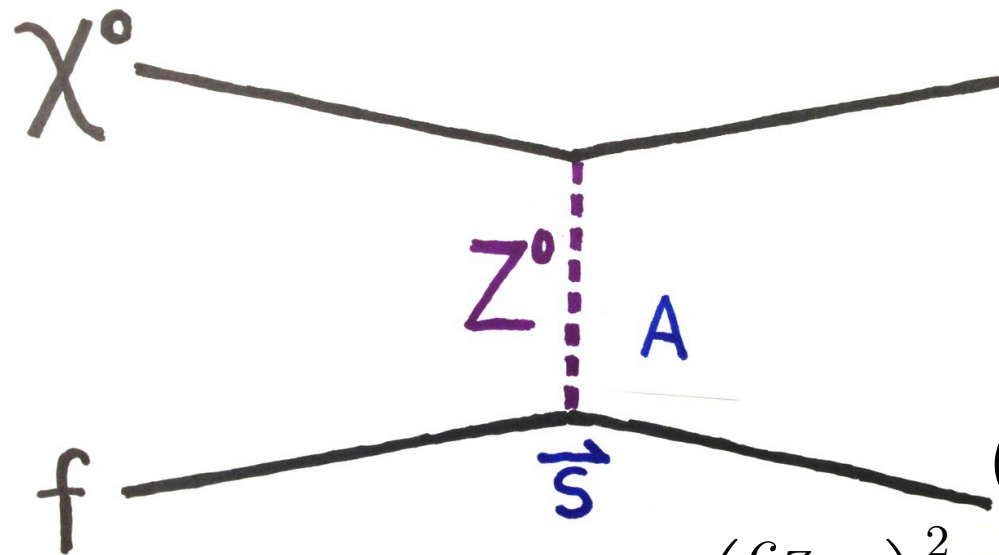
Evolution of the WIMP–Nucleon σ_{SI}





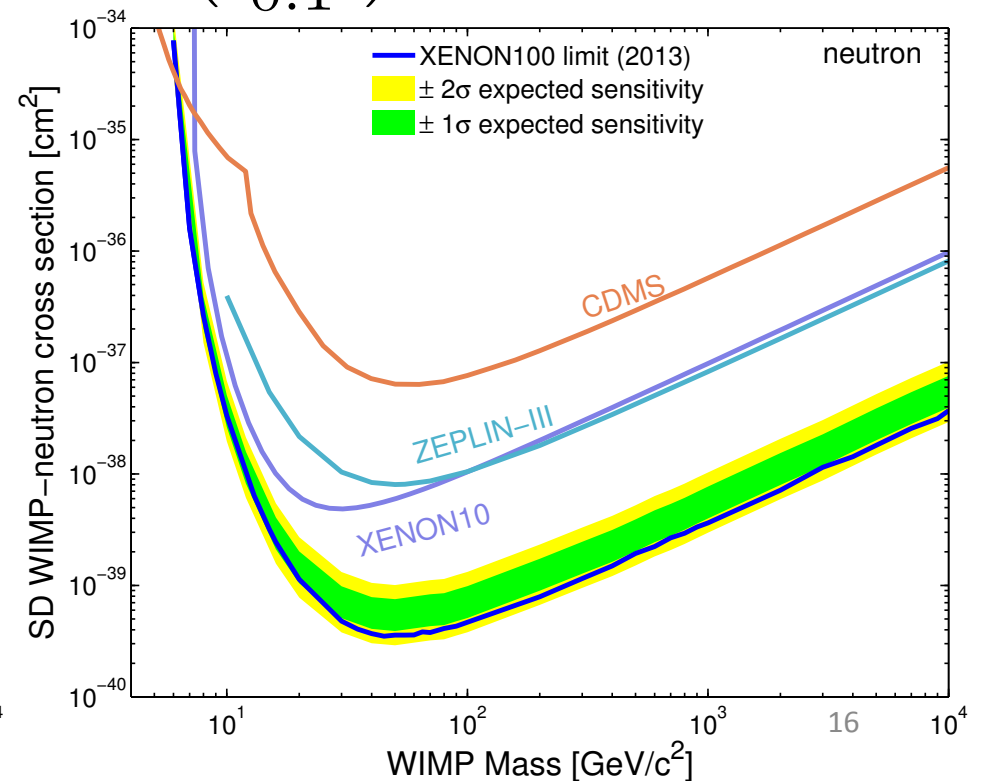
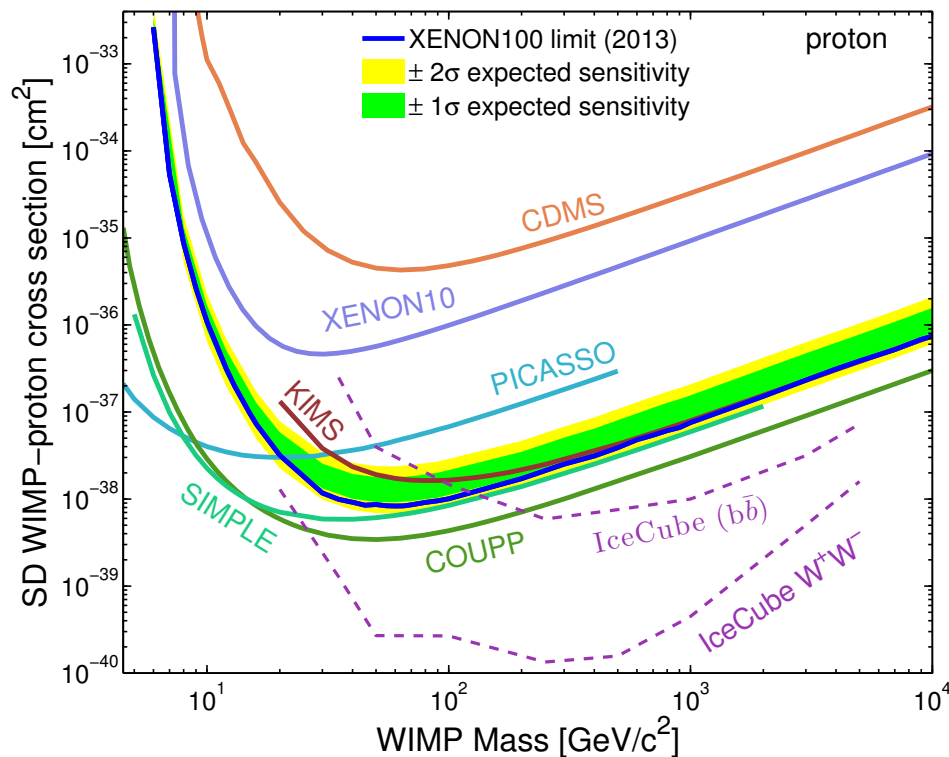






$$\sigma_{\text{SD}} = 3 \times 10^{-39} \text{ cm}^2 \left(\frac{c_{Z\chi\chi}}{0.1} \right)^2$$

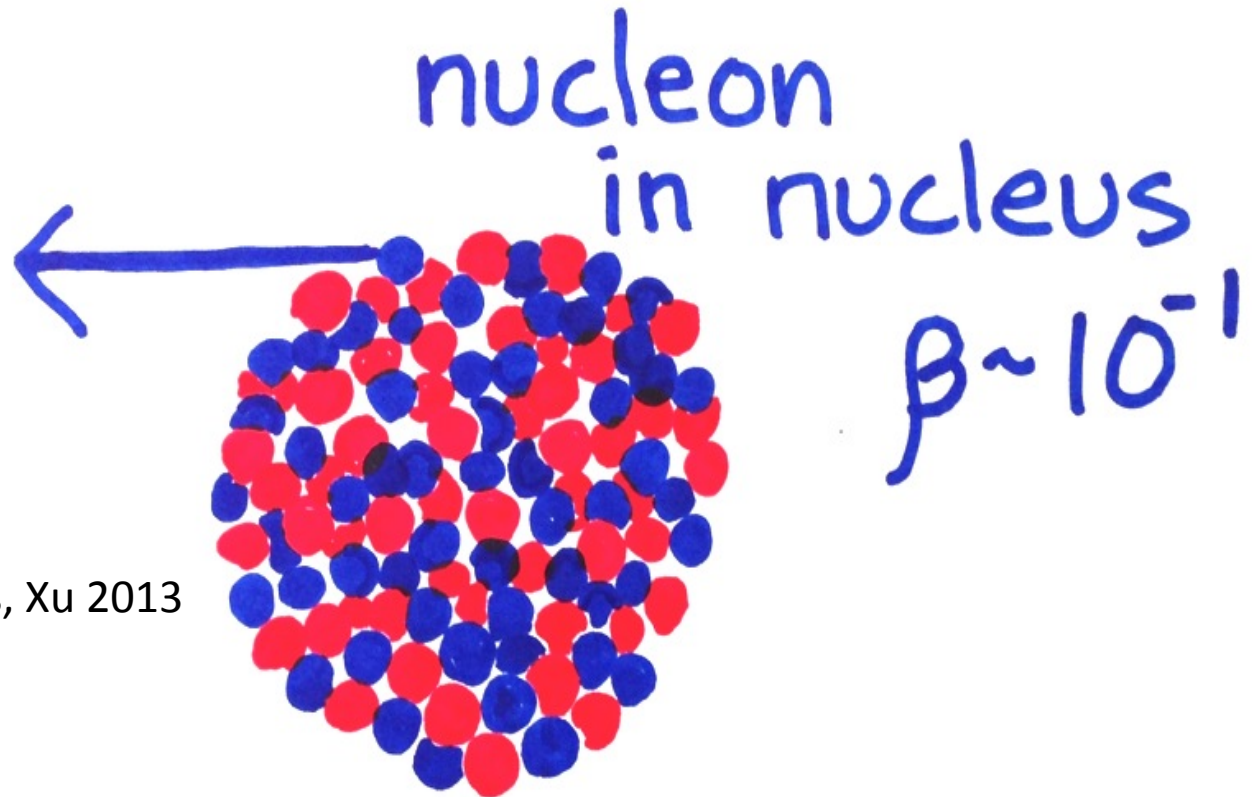
(unpaired nucleon
in nucleus; p – F/
Na/I, n – Ge/Xe)



More thoughtful nuclear physics

χ^0
 $\beta \sim 10^{-3}$

Fitzpatrick, Haxton, Katz, Lubbers, Xu 2013



Electrophilic dark matter

Kopp, Niro, Schwetz, Zupan 2009

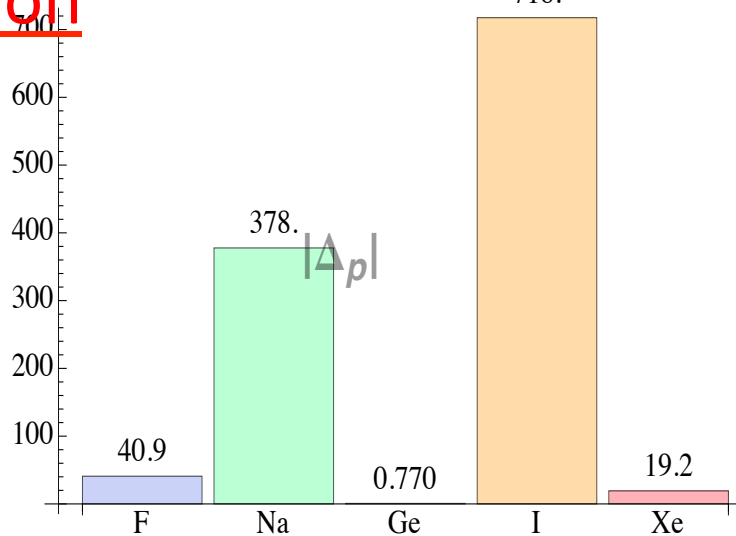
electron
in atom
 $\beta \sim 10^{-2}$

p

Δ

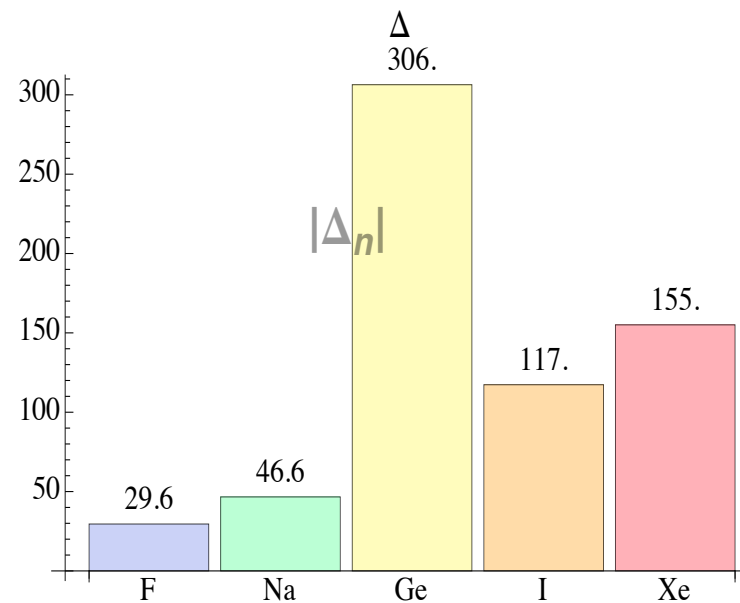
Interaction

\vec{L}



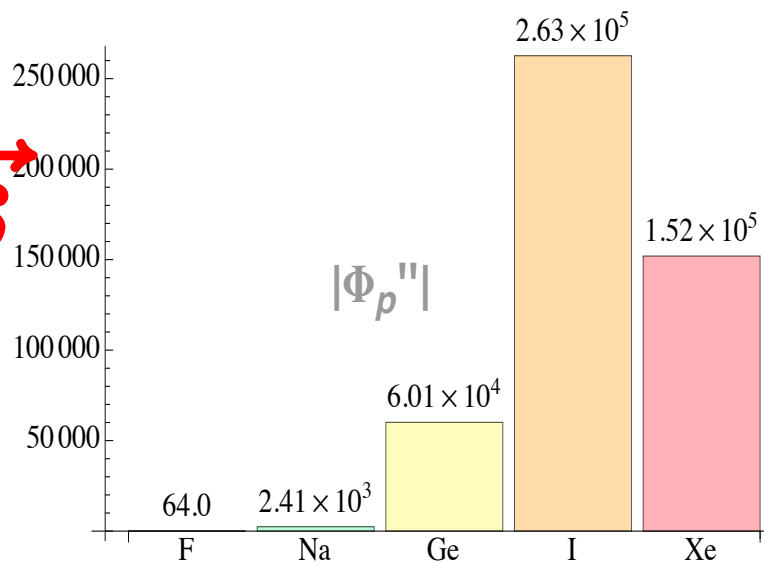
n

Δ

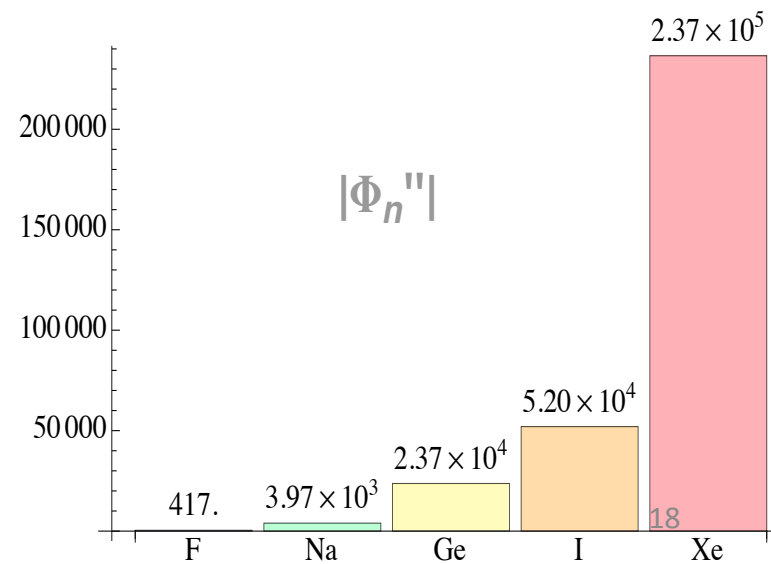


Φ''

$\vec{L} \cdot \vec{s}$



Φ''



PASAG 2009 – Defined Generations

- For dark matter direct detection: next-generation (G2) facilities capable of reaching sensitivity levels better than 10^{-46} cm^2 (about a factor 400 better than present-day limits and a factor ~ 10 better than expected for the experiments already under construction), and third-generation (G3) experiments surpassing the 10^{-47} cm^2 level. Details are different for the different technologies. G2 experiments would have typical target masses of approximately one ton, with a construction and operation cost in the range of \$15M-\$20M, and G3 experiments would have target masses of many tons with a construction and operation cost around \$50M.

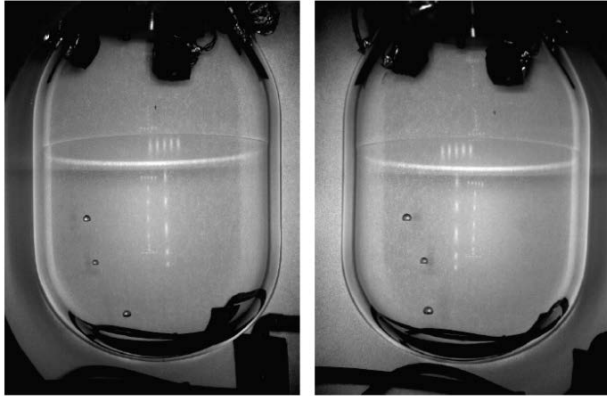
Scenario A (constant level of effort at the FY08 level)

In dark matter, the current world-leading program is maintained, but world leadership would be lost toward the end of the decade:

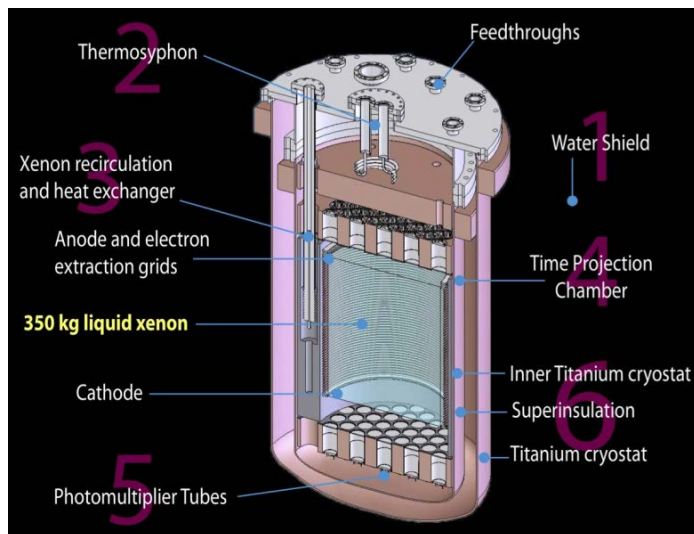
- Two G2 experiments and the 100-kg SuperCDMS-SNOLAB experiment are supported. The technology selection for the G2 experiments should occur soon enough to allow the construction of at least one G2 experiment to start as early as FY13.
- No G3 experiments can be started in this decade. Progress will be slowed, risking loss of U.S. world leadership. However, due to the risk of picking the wrong technology, this is preferable to descope to only one G2 experiment.

DOE “First Generation” (G1) DM Experiments (NSF too)

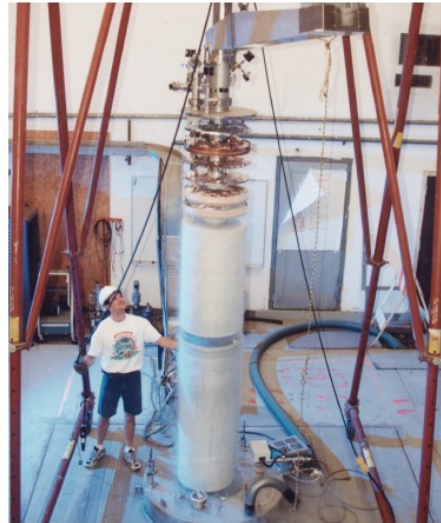
M. Salamon, 3/2013, HEPAP



COUPP Bubble Chamber – at SNOLAB
Operating 40-80 kg CF_3I



Large Underground Xenon (LUX) detector –
Sanford Lab, Homestake mine, commissioning
350 kg L Xe (120 kg Fiducial) – Result

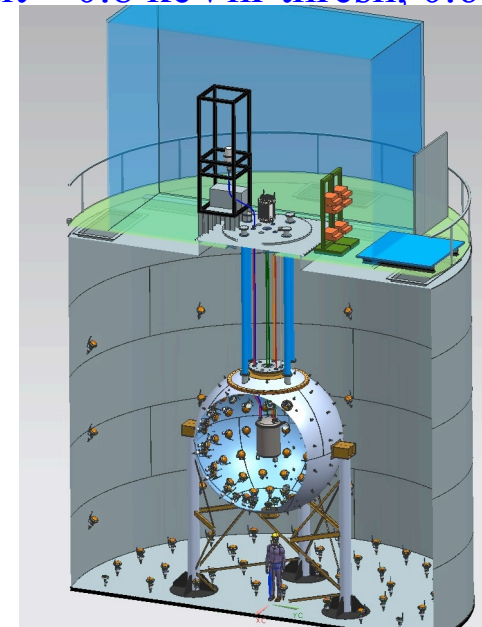


Axion Dark Matter eXperiment
(ADMX) Phase-2a at U.Washington
-commissioning; start science run
in summer
Operating



Cryogenic Dark
Matter Search
(CDMS) at
Soudan mine -
germanium
detectors
- operating

Operating 9 kg Ge
Result – 0.8 keVnr thresh, 0.6 kg

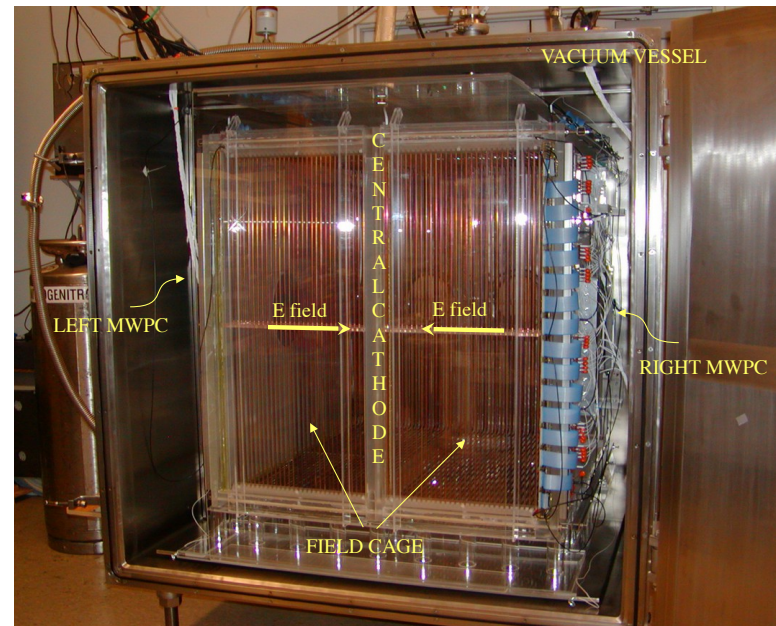


DarkSide-50 – Dual-Phase liquid argon TPC at LNGS;
Operating 50 kg Liquid Argon (^{39}Ar Depl.)

NSF DM Experiments



XENON100— operating since 2009, LNGS.
Liquid Xenon 161 kg Total, 32-40 kg Fiducial,
Numerous publications.



DRIFT-II – operating,
Boulby (UK), 1/30 kg
fiducial gas $\text{CF}_4 + \text{CS}_2$.
Directionality.

G2

2013 R&D – proposals very recently. ‘Downselect’ in 1/2014.

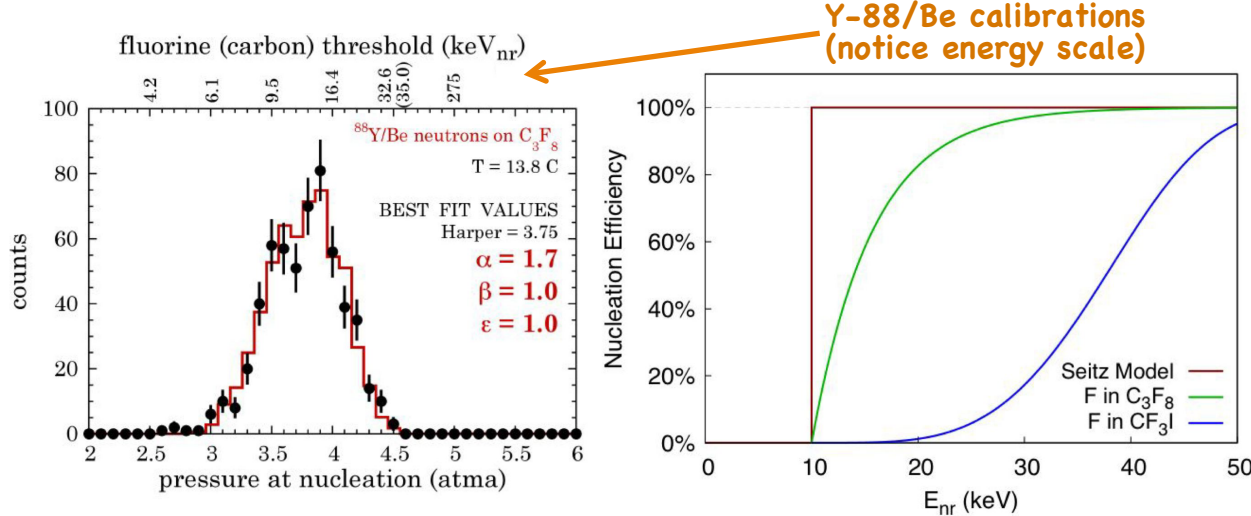
FY 2014-2017 Construction + several (3-5) years operations

- PICO250 (Picasso + COUPP) 400 kg C_3F_8 /640 kg CF_3I , SNOLAB
- ADMX-G2 – Axion Detection, Univ. Washington
- SuperCDMS-SNOLAB – 110 kg Ge/Si, SNOLAB
- LZ (LUX + ZEPLIN) – 7000 kg Liquid Xe, SURF (Homestake)
- Darkside-G2 – 5000 kg Liquid Ar, LNGS

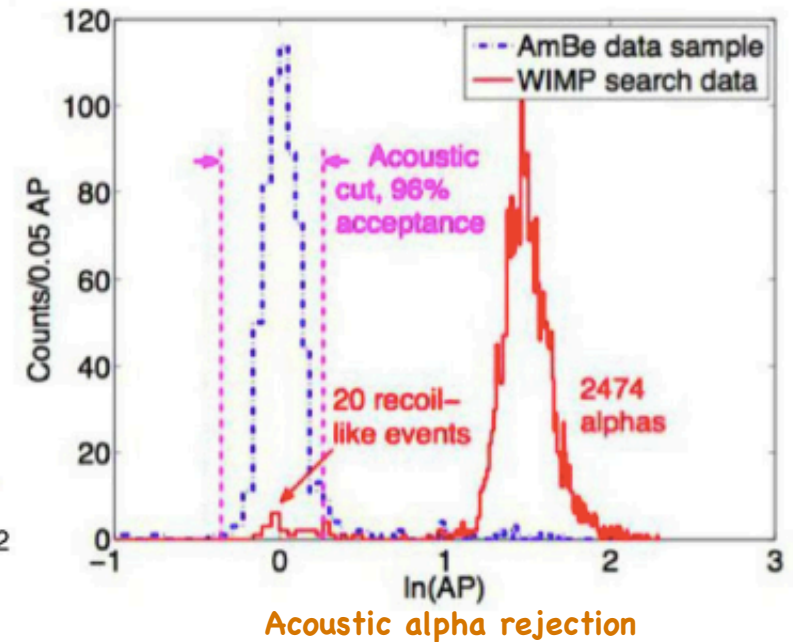
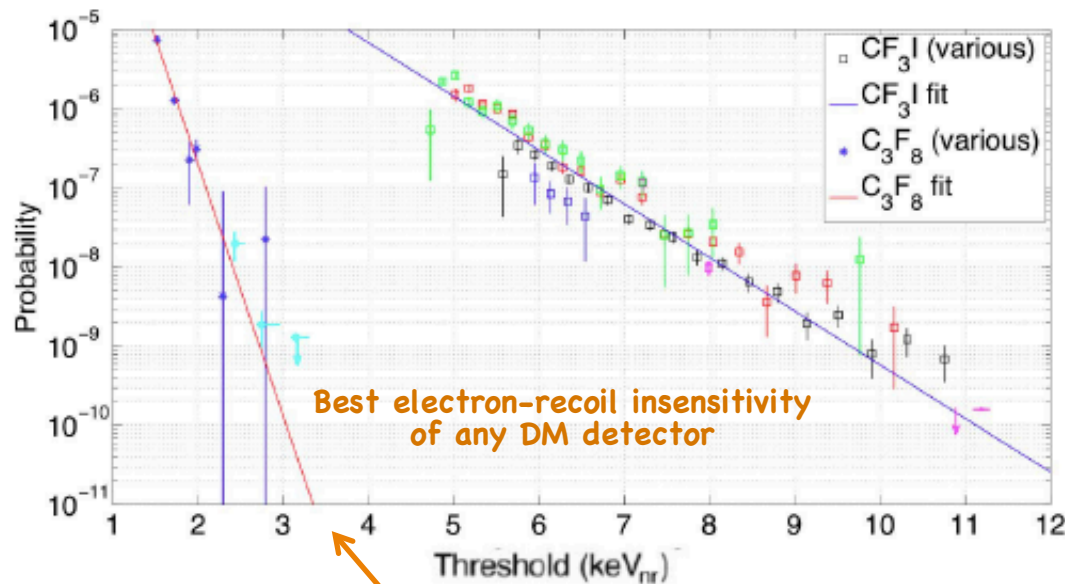
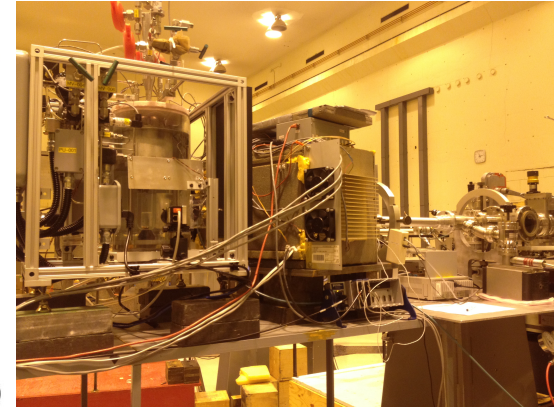
G2 w/o R&D Award

- XENON1T Upgrade – 7000 kg Liquid Xe, LNGS
– \$7.4M NSF, \$7M Other for XENON1T
- DRIFT-III – 1 kg Fid. CF_4/CS_2 (Gas, Direction), Boulby UK
- DM-Ice 250 North – 250 kg NaI, LNGS

PICO-250 - Exhaustive characterizations of response



Monochromatic $\sim 90\text{ keV}$ neutrons from Tandem @ Montreal

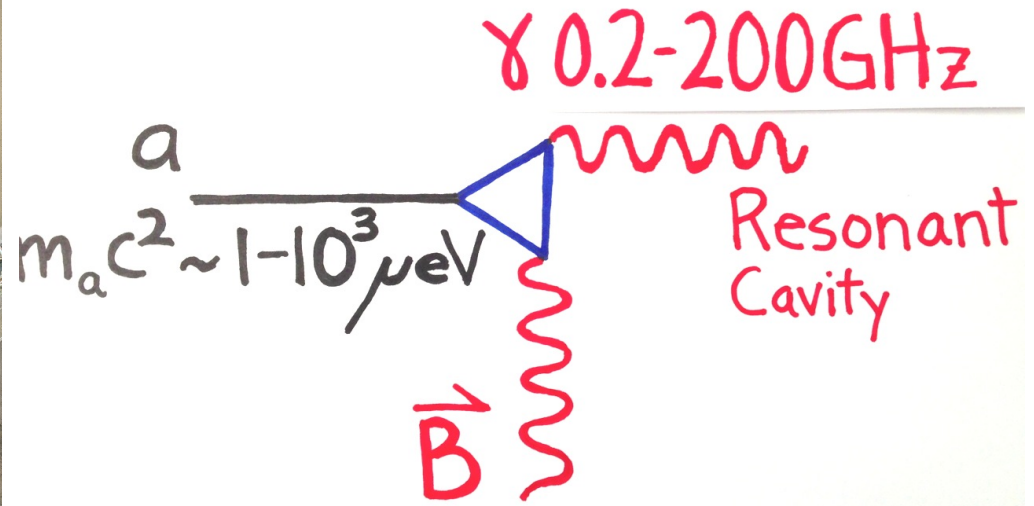


ADMX – G2

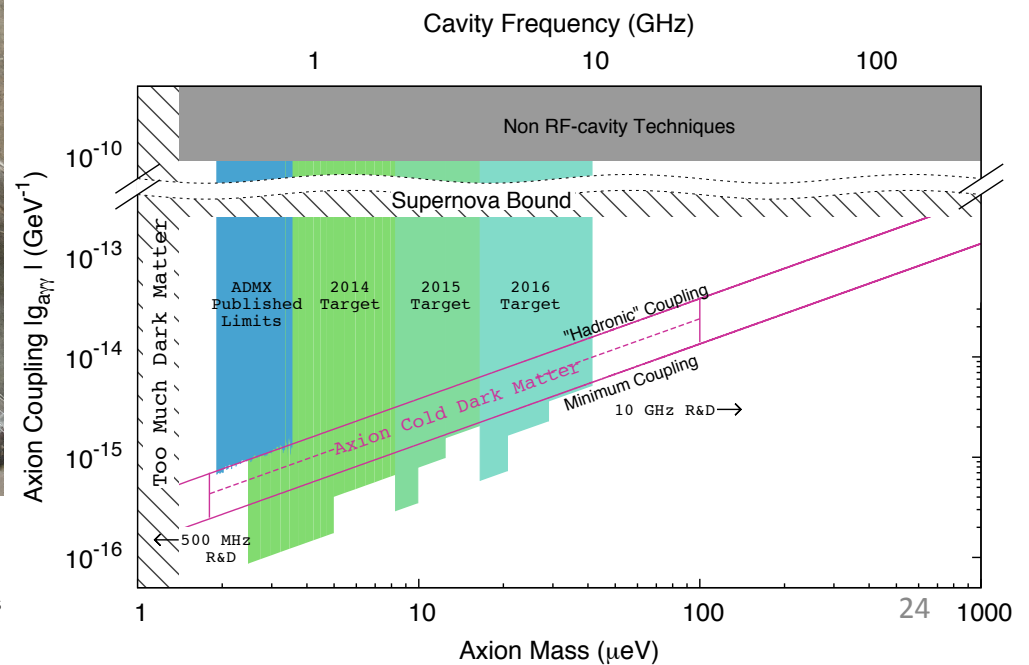


Dark Matter's Dark Horse

A rare yes/no effort promises to prove either that hypothetical particles called axions are the universe's elusive dark matter—or that they can't be

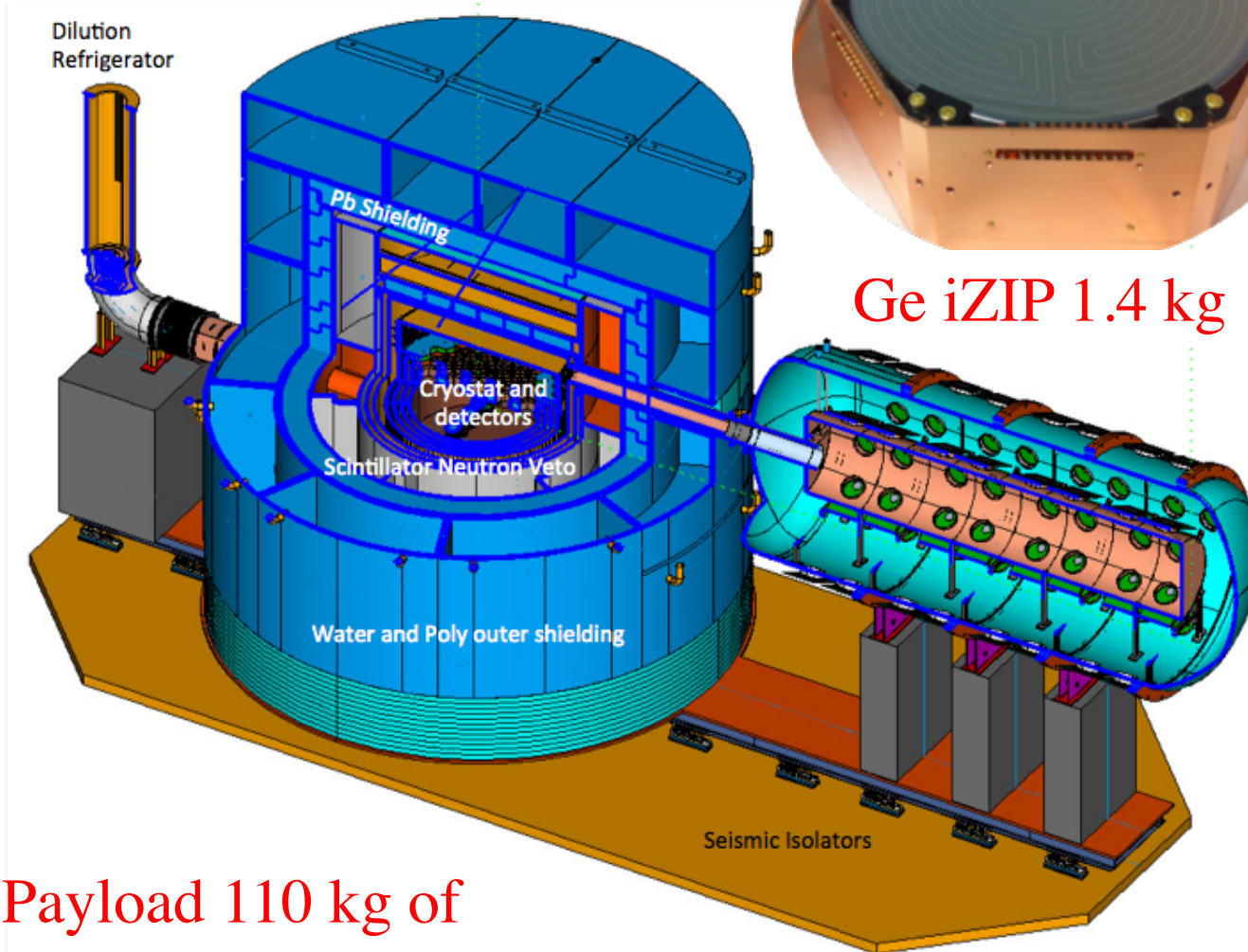


ADMX Achieved and Projected Sensitivity

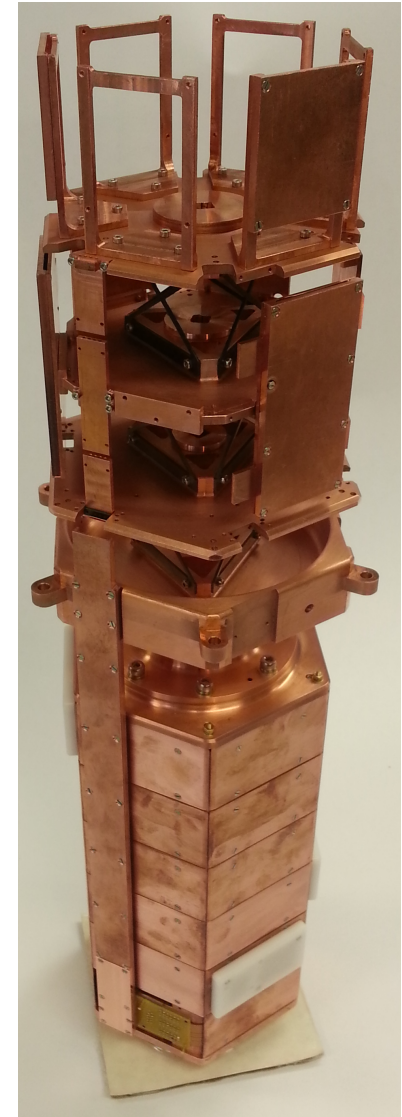


SuperCDMS SNOLAB Experiment

- SNOLAB 6010 mwe

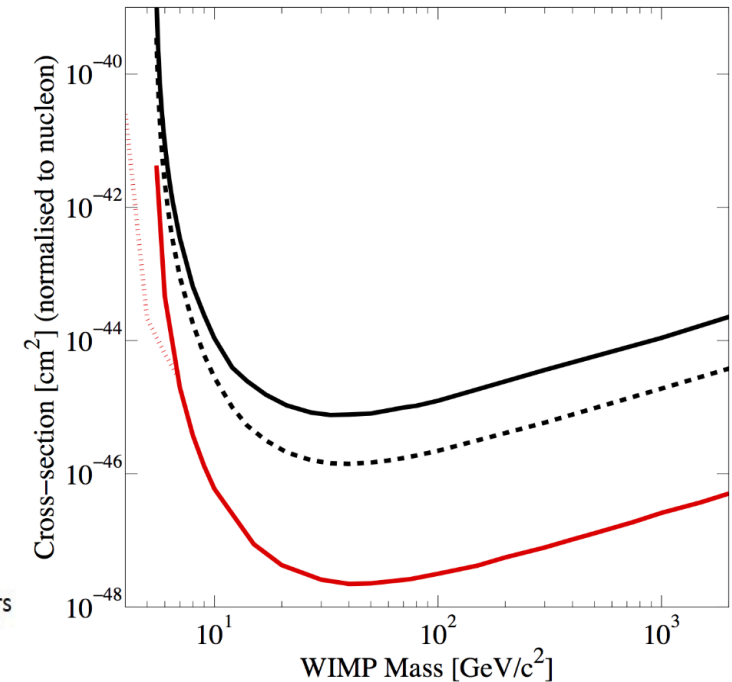
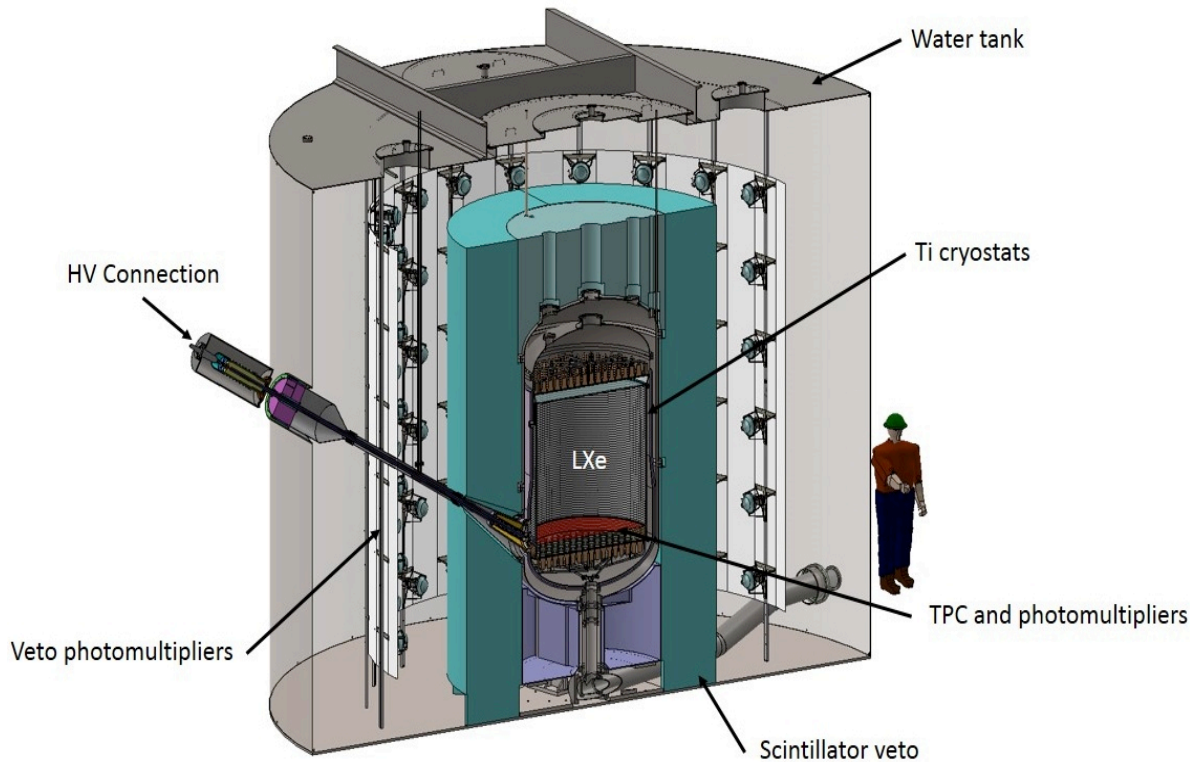


Payload 110 kg of
Ge & Si - capacity 400 kg Ge



Ge Tower 8.4 kg

LUX – ZEPLIN (LZ)



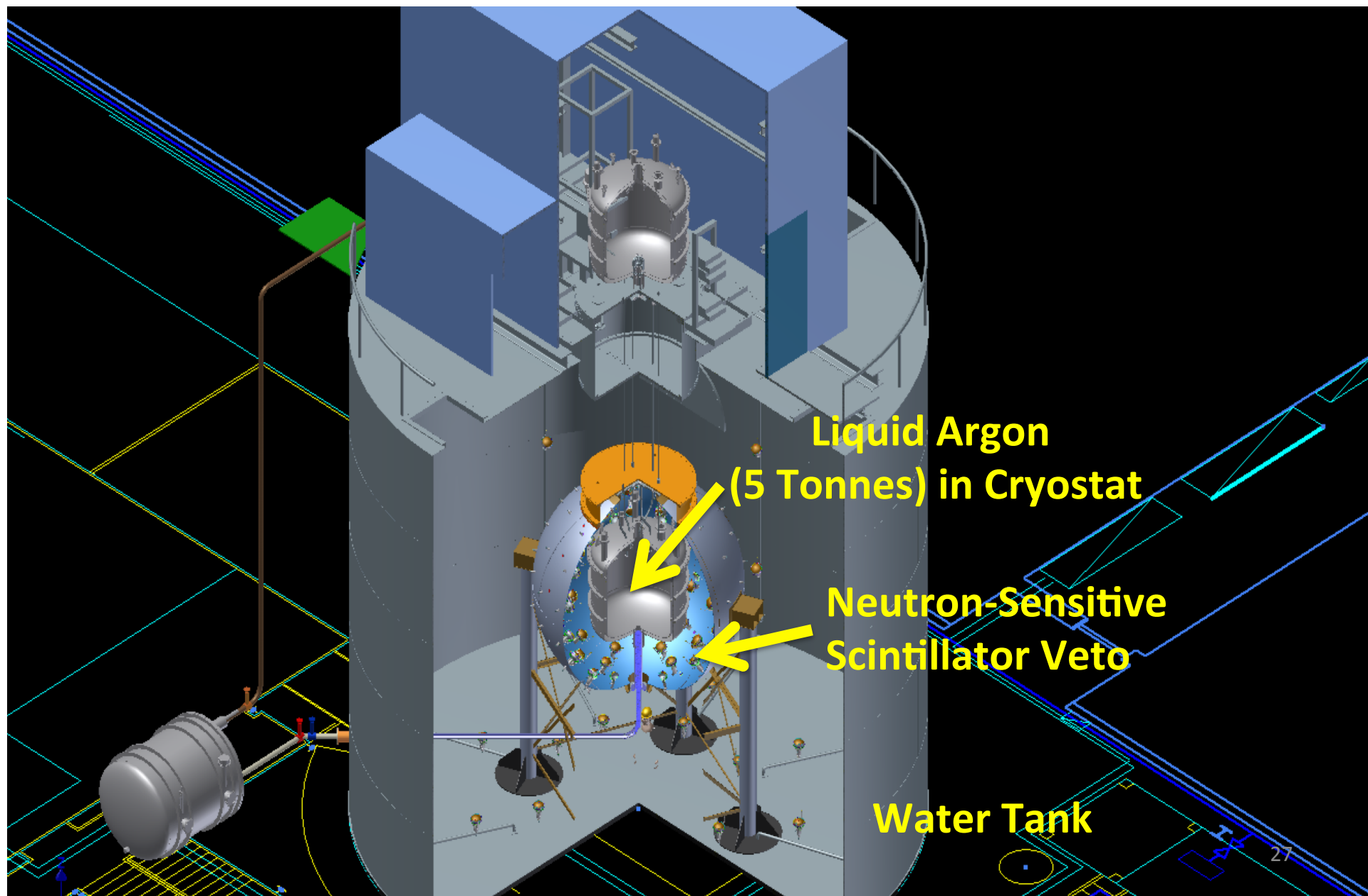
Projected 90% confidence limits on the spin-independent elastic WIMP-nucleon cross sections for LZ (red) along with the current, world's-best limits from LUX (black) and the LUX 300 day projection (black dashed). The dashed red curve is based on S2 only analyses in LZ. LZ results are for 1,000 days.

7 tonnes of LXe inside dual – phase TPC

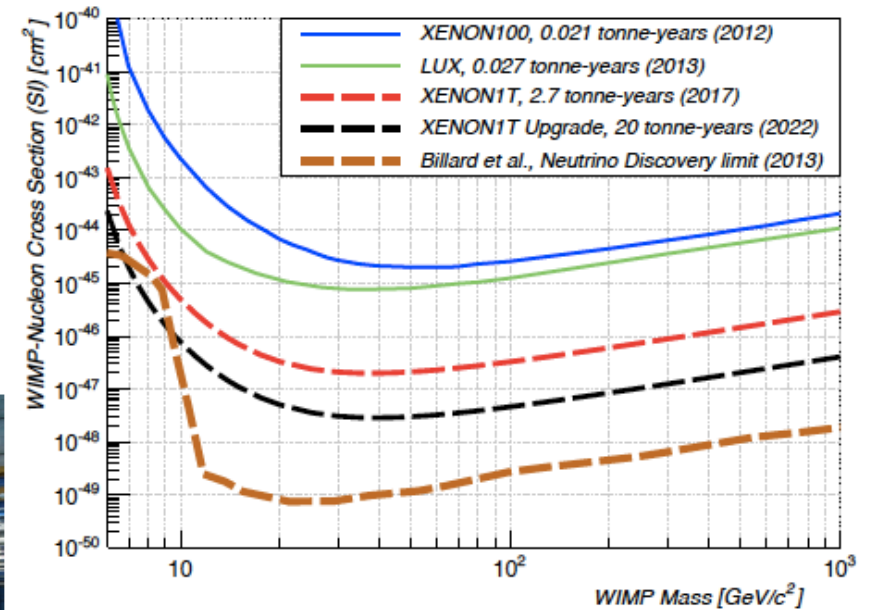
Scintillator veto substantially increases background rejection

Located in water tank (same as LUX) at Sanford Underground Research Facility (SURF), Lead, SD

Darkside-G2



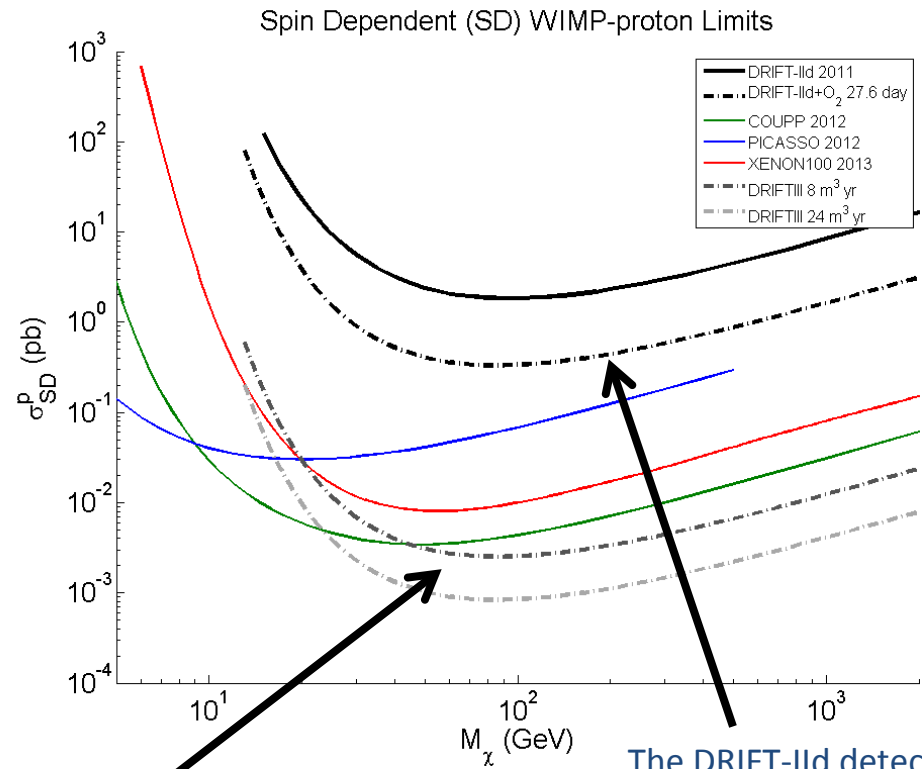
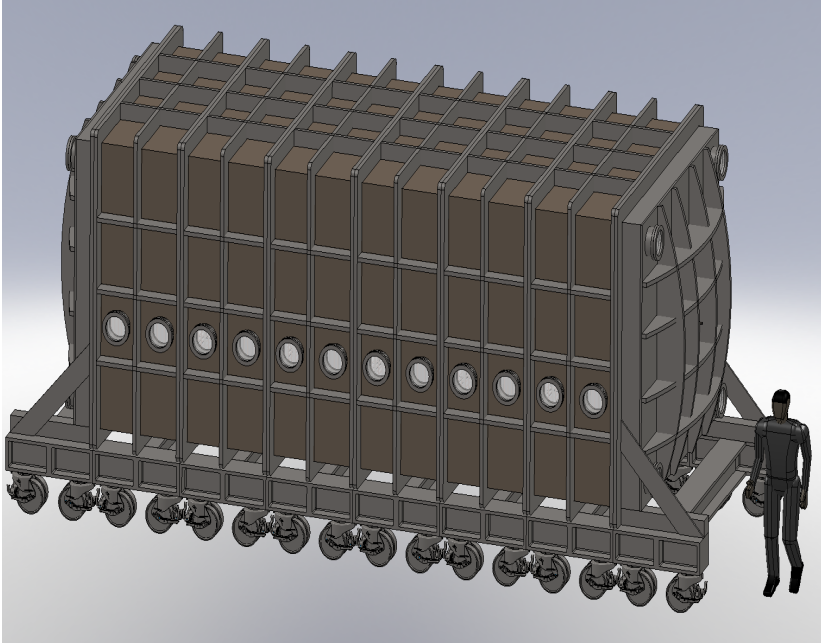
XENON1T + Upgrade



Xenon1T– construction, expected operations 2015, LNGS.
Liquid Xenon 3200 kg Total, 1300 kg Fiducial used for estimates.

Upgrade – Liquid Xenon to 7000 kg Total, reuse cryostat & water tank

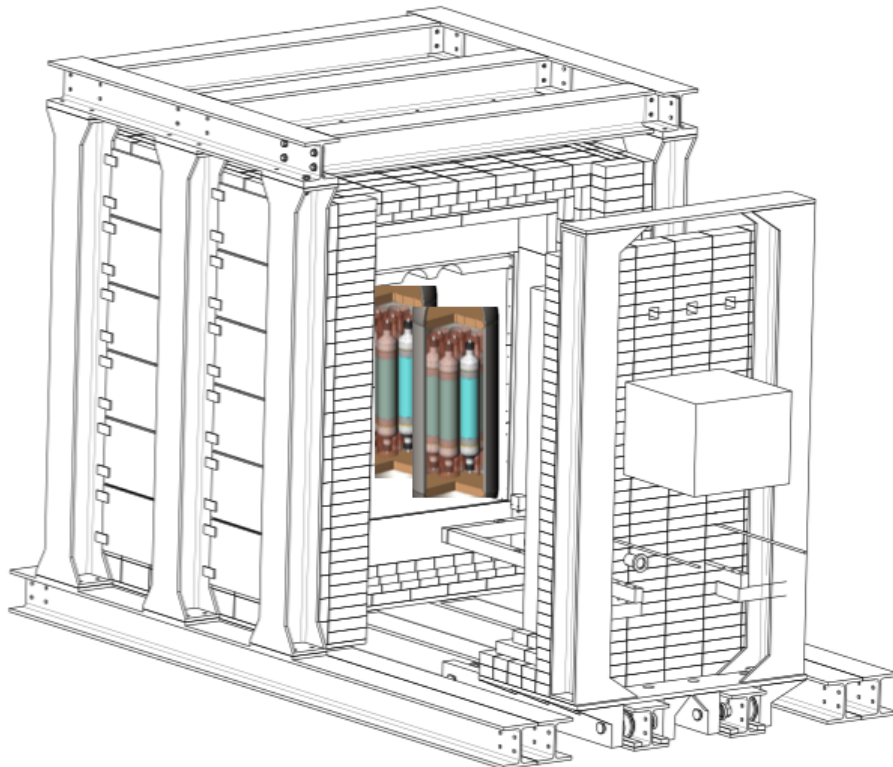
DRIFT-III



DRIFT is now severely volume limited. DRIFT-III will be 30x the size of the current DRIFT-II class detectors.

The DRIFT-II d detector in Boulby is now running *background-free*. With only 27.6 days our limits have improved by a factor of almost 10.

DM-ICE 250 North



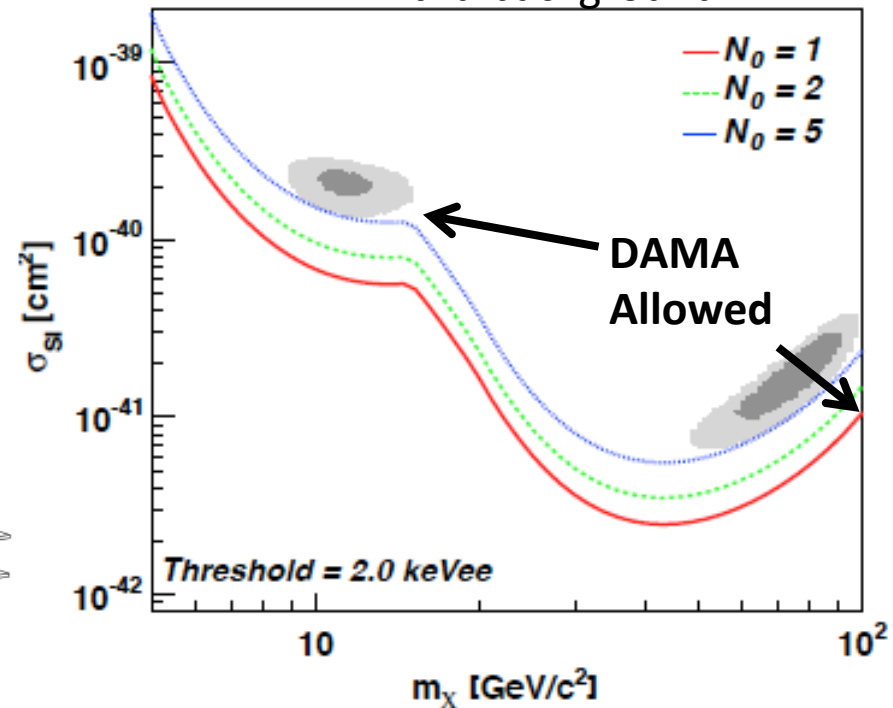
Directly test DAMA's assertion that the observed annual modulation is due to dark matter & understand its origin

250 kg NaI

Movable to South Pole

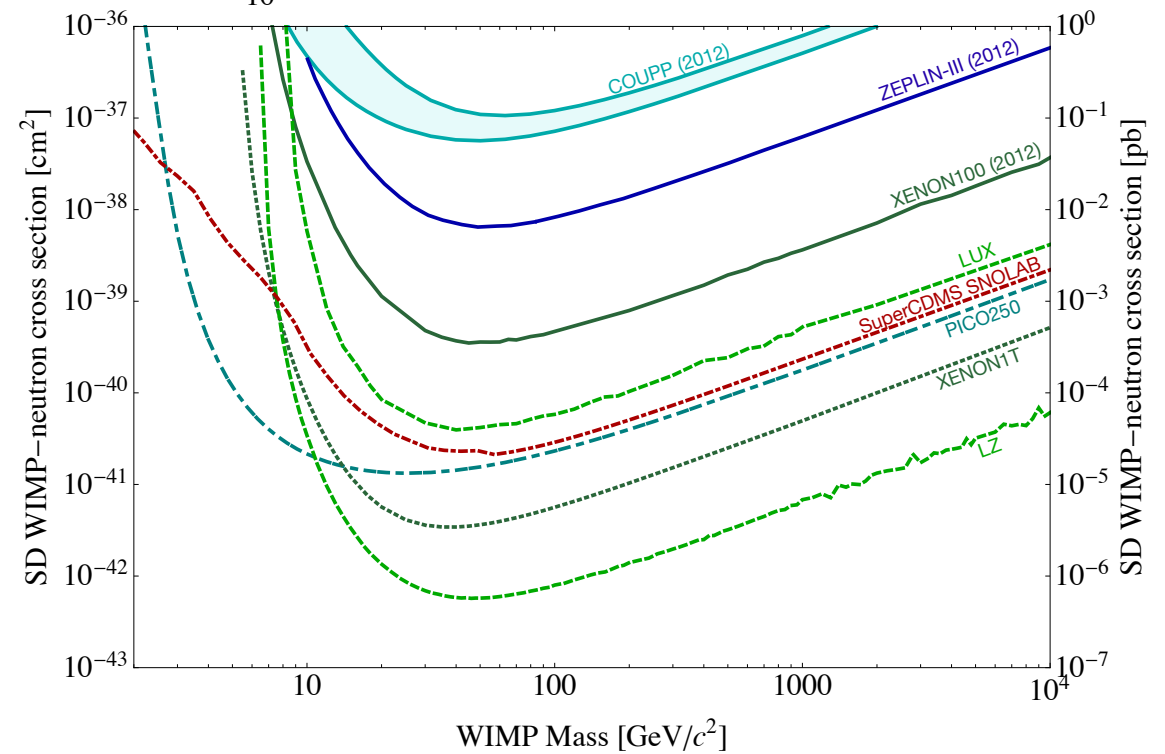
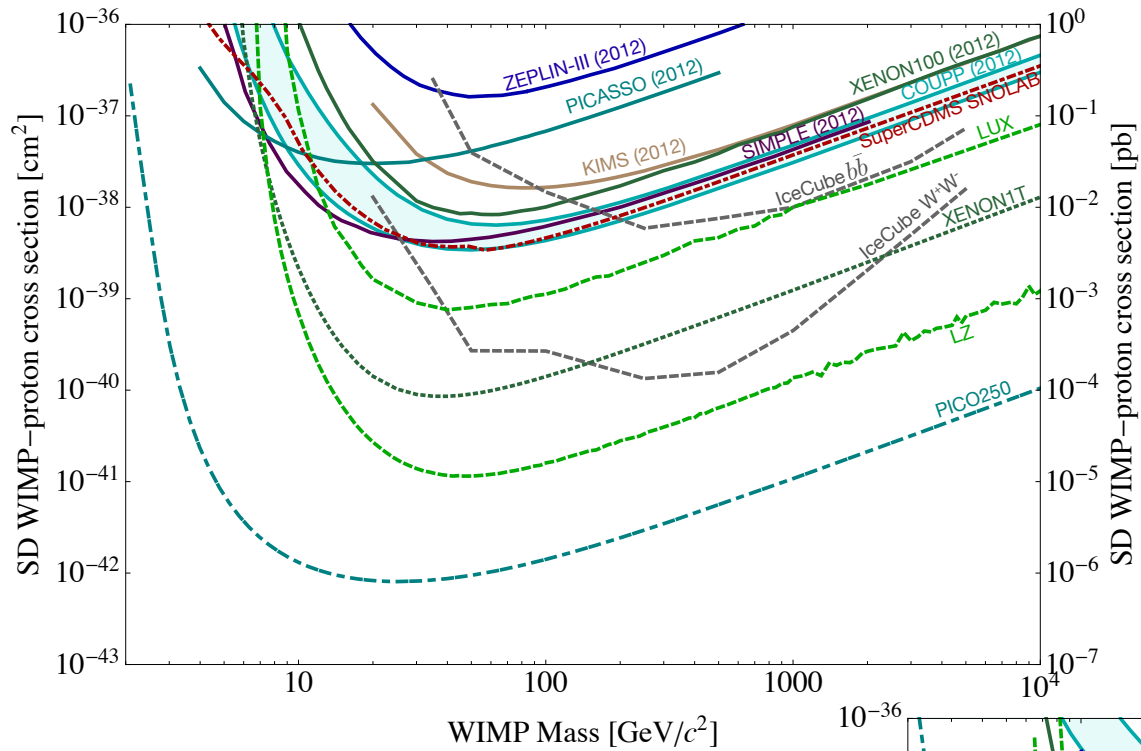
500 kg•years

(2 - 4 keV) with 1, 2, and 5 dru background



Northern Hemisphere	Gran Sasso DM-Ice North 250kg Proposed	Gran Sasso SABRE (Princeton) R&D	Canfranc ANAIS 250 kg starting in 2014?	PICO-LON KIMS
Southern Hemisphere	South Pole DM-Ice 17 kg prototype running	ANDES Lab (proposed) expected start 2017	under development	

Spin Dependent



G2 People And Money

Project	People		Money (\$ Million)			
	Head Ct.	FTE	DOE	NSF	Other	Agency Total
A	105		0	10.3	7	10.3
B	80		17.9	10.6	3.4	28.5
C	30		0	4	0	4
D	60	55	3.7	2.7-3.2	1.5-2	6.4-6.9
E	30		0	2	0	2
F	142		7	16		23
G	127		22.6	11.5	20.9	34.1
H		6	5	0	0	5
Total	>574		56.2	57.1-57.6	>32.8-33.3	113.3-113.5

Estimate Available: 24 10-22 34-46

March Letter to Agencies

To: James Siegrist, Director DOE HEP; Fleming Crim, AD NSF MPS
Cc: Kathy Turner, Michael Salamon, Jim Whitmore, Jean Cottam Allen
Fr: Direct Detection community scientists
Sb: Need to increase funds supporting G2 experiments within DOE and NSF

In community discussions during the Cosmic Frontier Workshop at SLAC (March 6-8, 2013) about the expected budgetary profile presented by the agencies, it became clear that the US is in danger of losing its lead in the Dark Matter field, just as we begin to probe parameter space for what could be the paradigm-changing discovery. If we remain within the planned funding profile, we can fund at most two major experiments, and then only by forcing them to reduce substantially their capabilities and science reach. The addition of roughly \$20M at DOE HEP and a commensurate budget at NSF, would greatly increase the chance for our US community to convincingly discover dark matter. This would allow experiments with complementary capabilities and different systematics, more complete cross checks in regions of sensitivity overlap, and a more effective program to explore the technologies that will be selected for G3.

The scientific and technological justification for this increase in funding has been substantially strengthened over this past year (see presentations at Cosmic Frontier Workshop <https://indico.fnal.gov/conferenceTimeTable.py?confId=6199#20130307>). We have input from LHC and from indirect searches which impact the G2 parameter space, and we have the cost estimates for the G2 R&D programs selected as "must fund" by the FOA (Funding Opportunity Announcement) review committee.

As detailed in the DOE FOA, after the \$7M in FY13 for R&D, the funding profile from the requested MIE within the DOE HEP plans for \$13M, \$9M and \$9M in each of FY14, FY15 and FY16. Our request is to significantly increase this funding by roughly doubling the amounts in FY15 and FY16 or, if that is not possible, by continuing the funding profile at similar levels through FY17 and FY18. As Jim Whitmore outlined in his presentation to DURA on Tuesday, March 5, 2013, the NSF has a different budgetary process. However, given the experience of the Dear Colleague Letter on Underground Science, it is also likely that

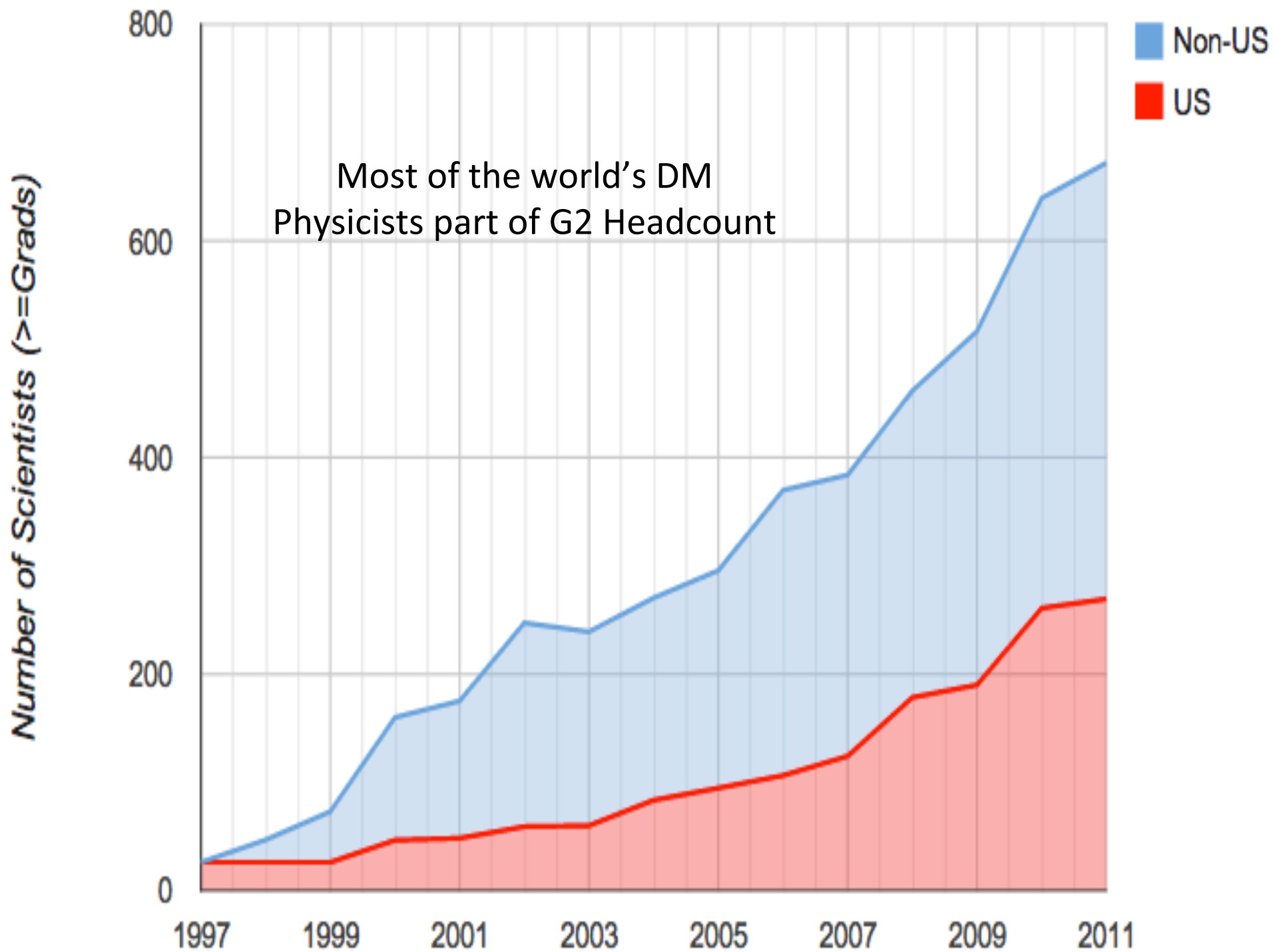
the amount requested from NSF for G2 joint experiments will also far exceed the routine investment capability of Particle and Nuclear Astrophysics.

Within an expanded but still modest funding profile at both DOE and NSF, the US has the opportunity to continue its leadership of the dark matter searches, and reap the rewards from the much-anticipated discovery of WIMPs or axions. We hope you can find a way to bolster the US G2 program to allow the suite of experiments needed to make these discoveries,

Dan Akerib
Adam Bernstein
Blas Cabrera
Frank Calaprice
Juan Collar
Prisca Cushman
Enectali Figueroa-Feliciano
Rick Gaitskell
Gil Gilchriese
Sunil Golwala
Bob Jacobsen
Dan McKinsey
Harry Nelson
Richard Partridge
Bernard Sadoulet
Peter Sorensen
Tom Shutt
Mani Tripathi
Karl van Bibber
Bob Webb
Mike Witherell
Frank Wolfs

Responses posted at

<http://www.snowmass2013.org/tiki-index.php?page=Letters>



Other Large World Experiments

- DEAP - single phase Liquid Argon (operations in 2014)
 - 3600 kg, 1000 kg fiducial, Pulse Shape Discrimination
 - Head Count – about 70
 - SNOLAB, Canada, UK
 - Prove ^{39}Ar rejection (as will Darkside-50 (TPC))
- MiniCLEAN – single phase Liquid Argon (operations in 2014)
 - 500 kg, 150 kg fiducial, Pulse Shape Discrimination
 - SNOLAB, US, UK
 - Prove ^{39}Ar rejection with dedicated ^{39}Ar injection
- XMASS – single phase Liquid Xenon (operating)
 - 100 kg Fiducial, 1000 kg (2015) [835 kg, 5000 kg]
 - Head Count – about 50
 - Kamioka, Japan
- PandaX – dual phase Liquid Xenon TPC
 - 25 kg (2013), 300 kg (2014); then 1000 kg (Phase 2)
 - Head Count – about 40
 - JinPing (deep and radiopure) China, US

R & D

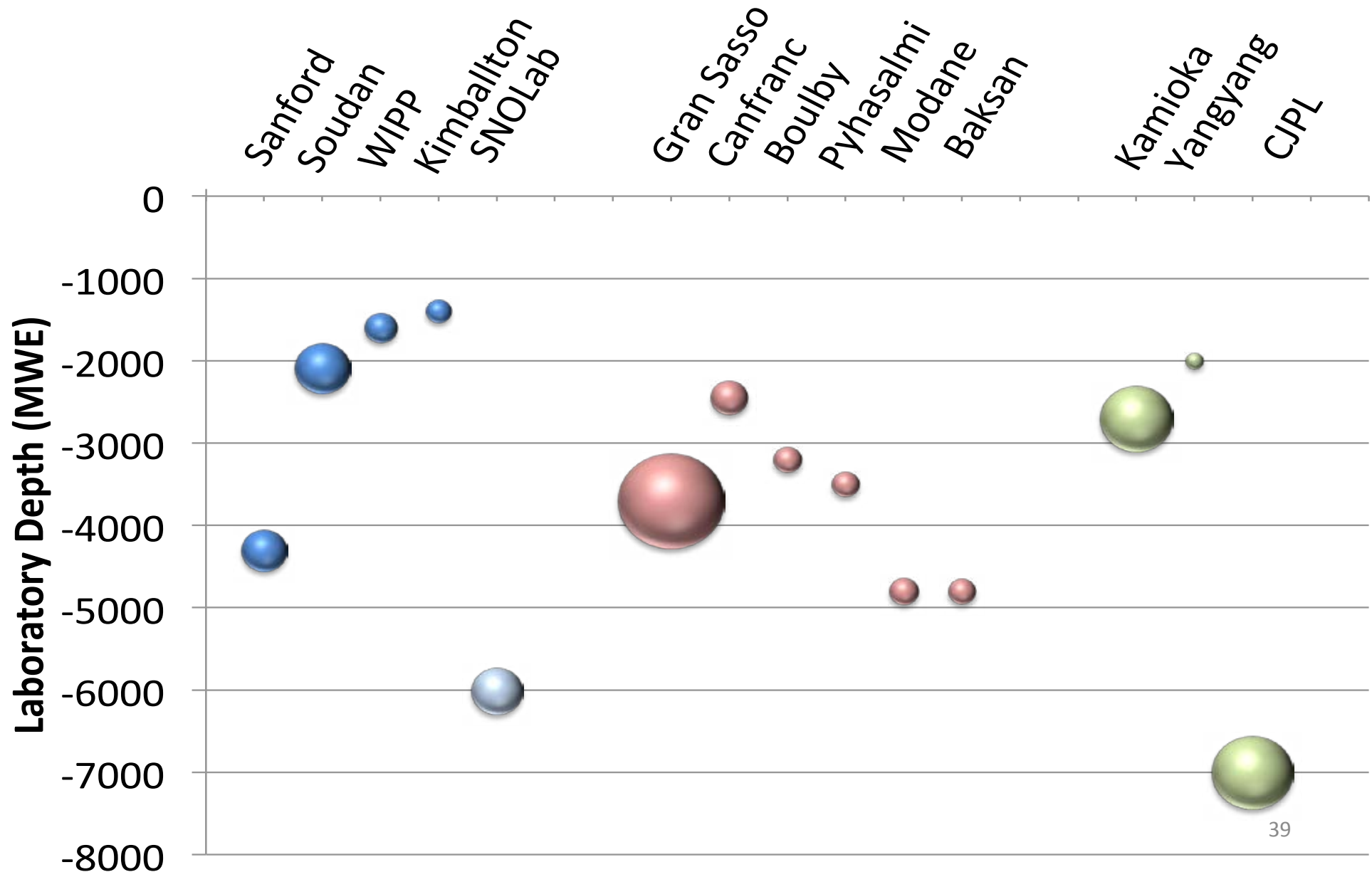
- Officially... DONE. Project Proposals Submitted
- Long duration exposures of Darkside-50, DEAP, and COUPP-60 are important
- G2 will teach us a lot; upgrades desirable
- Radiopurity – G2 done project by project
 - Double beta decay has achieved levels 1/100 of G1
 - Successor to G2 will need more programmatic approach, and will need to commence well in advance of G3
 - Barrier to collaborations with Nuclear Physics has been counterproductive

`Benefit US Facilities & Development of Key US Capabilities'

- The US has generally led the world in direct dark matter experimentation over the past 30 years.
- More deep underground floor space is right now available outside the US than inside the US.
- A portion of the direct dark matter community strongly supports experiments sited in the US; another portion follows underground facility availability.

Labs – Size of Sphere is Volume

Comparison of Laboratory Sizes



G3

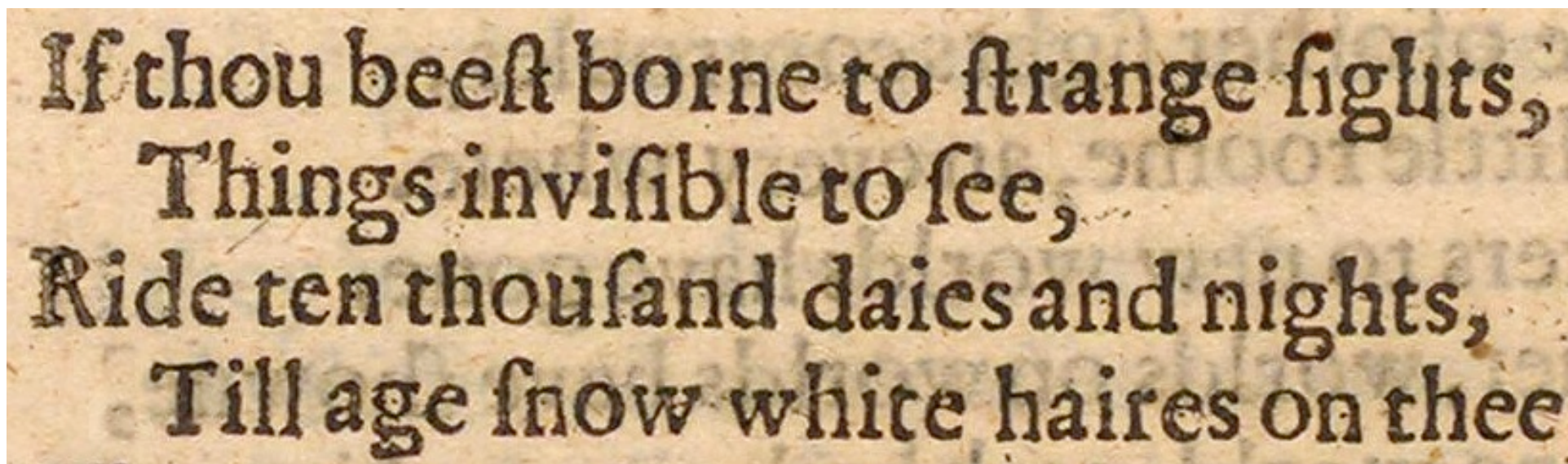
- G2 Program through about 2020
- G3 – something like 10's of tonnes, \$100 million
- Get into the irreducible neutrino background for SI
- 1-3 in the world
- No US underground facility large enough right now to host
- Depth: some would say SURF/Gran Sasso depth sufficient, others disagree

Thanks!

- Mike Witherell, Blas Cabrera, Peter Meyers, Mike Crisler, Juan Collar, Stephen Pordes, Dan McKinsey, Elena Aprile, Gil Gilchriese, Tom Shutt, Dan McKinsey, Luca Grandi, Cristian Galbiati, Andrew Hime, Wick Haxton, Dan Snowden-Ifft, Reina Maruyama
- All mistakes are mine, and my apologies for them

Conclusions

- WIMP (and axion) Direct Dark Matter Detection has been a hotbed of US Enterprise and Innovation for the past 26 years.
- We have led the world.
- We know budgets are tight.
- Few (if any) endeavors have this sector's potential for startling discovery.



If thou beest borne to strange fights,
Things invifible to fee,
Ride ten thousand daies and nights,
Till age fnow white haires on thee